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A SUBSONIC METHOD FOR PREDICTING THE SEPARATION TRAJECTORIES OF AIRCRAFT STORES IN THE PITCH PLANE

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Wright-Patterson Air Force Base, Ohio

September 1974

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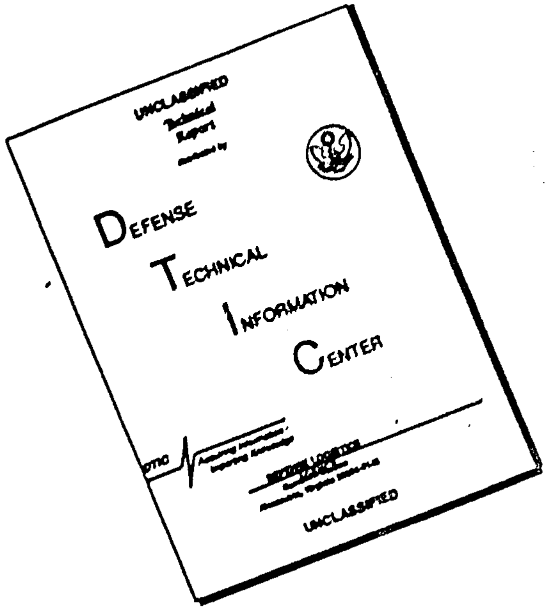

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developed and used to calculate trajectories for the M-117 bomb as carried on the inboard pylon of the F-4E. Comparisons of these trajectory profiles with wind tunnel captive-trajectory test results and existing theory are made. A user's guide and computer listing, excluding those subroutines due to F. Dan Fernandes, are given. Recommendations are made for possible improvements to the newly developed method.

A SUBSONIC METHOD FOR PREDICTING THE SEPARATION TRAJECTORIES OF AIRCRAFT STORES IN THE PITCH PLANE

Thesis

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A SUBSONIC METHOD FOR PREDICTING THE SEPARATION TRAJECTORIES OF AIRCRAFT STORES IN THE PITCH PLANE

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

Joseph M. Manter, B.S.A.A.E.
Graduate Aeronautical Engineering

September 1974

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Preface

My main objective in this study was to develop a subsonic three-degree-of-freedom store separation prediction method which could incorporate, when available, experimentally determined, free-air, store static stability data. I am very satisfied with the results I have obtained with this method and I am hopeful that this longitudinal analysis of the separation problem will serve as a precursor to a six-degree-of-freedom analysis.

I would like to express my sincere gratitude for the assistance I received during the course of this study. I especially would like to thank my independent study advisor, Dr. Milton Franke, for his advice and guidance. I would also like to acknowledge my other two faculty advisors, Major Carl Stolberg and Captain James Karam for their constructive criticism. I owe a special debt of gratitude to Mr. Cal Dyer and Mr. Jerry Jenkins, both of AFFDL/FGC, for introducing me to the store separation problem and assisting me in the computation and analysis of theoretical data from existing methods. Finally, I would like to express my deepest appreciation to my wife, Ruth, for her patience and understanding, and to my daughters Jenny Lynn and Jill Kathleen for the time I took from them during these past twelve months.

Joseph M. Manter

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List of Symbols

Symbol	Description
b	Store reference dimension, ft
C_A	Store axial force coefficient, axial force/$\frac{1}{2}\rho_\infty V^2_{store} S_{ref}$
C_m	Store pitching moment coefficient, referenced to store center of gravity, pitching moment/$\frac{1}{2}\rho_\infty V^2_{store} S_{ref} b$
$C_{m_{DAMP}}$	Store pitching moment coefficient due to aerodynamic damping
C_{mq}	Store pitch damping derivative, $dC_m/d(qb/2\,V_{store})$
C_N	Store normal force coefficient, normal force/$\frac{1}{2}\rho_\infty V^2_{store} S_{ref}$
F_A	Sum of forces acting on store in axial direction, lb
$F_{AERO,A}$	Sum of aerodynamic forces acting on store in axial direction, lb
$F_{AERO,N}$	Sum of aerodynamic forces acting on store in normal direction, lb
F_{fa}	Free-air force acting on store in normal direction, lb
F_{int}	Interference force acting on store in normal direction, lb
F_N	Sum of forces acting on store in normal direction, lb
F_{z1}, F_{z2}	Ejector force due to ejectors one and two, respectively, lb
F_ξ, F_η	Sum of forces acting on store in ξ and η directions, respectively, lb

Symbol	Description
g	Acceleration due to gravity, ft/sec/sec
I_{yy}	Store moment of inertia about store y-axis, slug-ft^2
k	Store radius of gyration about store y-axis, ft
ℓ_{x1}, ℓ_{x2}	Ejector one and ejector two piston location distances relative to store center of gravity position forward of store center of gravity, ft
M_{AERO}	Pitching moment acting on store taken about store center of gravity, positive nose up, due to static aerodynamic forces, ft-lb
M_{DAMP}	Pitching moment acting on store taken about store center of gravity, positive nose up, due to aerodynamic damping, ft-lb
m_s	Store mass, slugs
M_θ	Sum of pitching moments on store taken about store center of gravity, positive nose up, ft-lb
q	Store angular velocity about store y-axis, rad/sec
S_{ref}	Store reference area, ft^2
V_{store}	Store total velocity, ft/sec
V_∞	Free stream velocity, ft/sec
X	x-separation distance of store center of gravity in fuselage wind-axis system, measured relative to store carriage position, ft
X_{CG}	Store center of gravity position, measured from nose of store, ft
X_{L1}, X_{L2}	Ejector piston location of ejectors one and two, respectively, positive forward of store center of gravity, ft
X_S, Y_S, Z_S	Store coordinate axes, ft

Symbol	Description
Z	z-separation distance of store center of gravity in fuselage wind-axis system, measured relative to store carriage position, ft
$Z_{E_{MAX}}$	Maximum ejector stroke travel, ft
α_B	Aircraft angle of attack, degrees
γ_B	Aircraft flight path angle, degrees
γ_S	Store flight path angle, degrees
θ	Store pitch angle, positive nose up, degrees
$\ddot{\theta}$	Store pitching acceleration, $d^2\theta/dt^2$, rad/sec/sec
ξ,η	Coordinates of store center of gravity in fuselage coordinate system, see Fig. 2, ft
$\ddot{\xi},\ddot{\eta}$	Accelerations of store center of gravity, relative to fuselage, ft/sec/sec
ρ_∞	Air density at simulated altitude, slugs/ft^3

Abstract

A subsonic three-degree-of-freedom method for predicting store separation trajectories is presented. The method combines the calculation of interference loading on aircraft stores due to F. Dan Fernandes with loads due to free air, ejector, and aerodynamic damping. Discussion of these loads is given, along with a presentation of the three-degree-of-freedom equations of motion and an approach to their solution. A computer program is developed and used to calculate trajectories for the M-117 bomb as carried on the inboard pylon of the F-4E. Comparisons of these trajectory profiles with wind tunnel captive-trajectory test results and existing theory are made. A user's guide and computer listing, excluding those subroutines due to F. Dan Fernandes, are given. Recommendations are made for possible improvements to the newly developed method.

A SUBSONIC METHOD FOR PREDICTING THE SEPARATION TRAJECTORIES OF AIRCRAFT STORES IN THE PITCH PLANE

I. Introduction

Problem

Today's aircraft are required to carry, and subsequently to release, many types of stores under many different flight conditions. The first 0.5 to 1.0 seconds is usually the critical period in determining a successful ejection under a given flight condition. An analytical method of predicting store separation trajectories during this critical time period is needed to serve as a preliminary design tool and to augment existing prediction methods.

Background

Store separation has been a matter of concern since the first World War I pilot attempted to throw a projectile from his open-canopied aircraft onto his enemy below. However, because of the relatively slow speeds of early flight, clearance from parent aircraft posed no great threat until the advent of the jet. At this time in aerial history, pilots were required to release externally carried stores from aircraft flying at higher and higher speeds (Ref 12:1,2).

Prediction techniques which have been developed are generally divided into three categories: full-scale flight testing, wind tunnel, and theoretical methods. Full-scale

flight testing has an obvious drawback in high costs, but, more importantly, can be quite hazardous to the pilot and his aircraft. Wind tunnel methods, including the simulated trajectory (Ref 2) and grid techniques (Ref 1), have proved to provide satisfactory results. However, because the only Air Force tunnel equipped for these techniques is scheduled many months in advance and because the already expensive costs of operating any wind tunnel is increasing, these methods cannot always be applied to present-day problems.

Theoretical methods have only recently been considered as an alternative to the first two approaches. While many authors have developed analytical methods of calculating flow fields under an aircraft (Ref 12:5-19), Goodwin, Nielsen, and Dillenius (Ref 7) and Goodwin, Dillenius, and Nielsen (Ref 8) have applied these analytical methods in developing the most comprehensive technique for computing separation trajectories. Fernandes (Refs 3 and 4), has devised methods for determining the interference loading on an aircraft store in the flow field of a parent aircraft. His development is incorporated in the present work.

Objective

The objective of this study is to develop a three-degree-of-freedom method to predict the separation trajectory of an aircraft store upon release from a parent aircraft flying at subsonic speeds. While previously developed techniques (Refs 7 and 8) have been entirely analytical in nature,

a goal of this study is to permit the use of experimental static stability data, when available, to determine the free-air loads on the store.

Another intent of this study is to allow the simulation and, therefore, the integrated effects, of a two-point ejector system in calculating the trajectory of an aircraft store. This again contrasts previously developed techniques which do not simulate the ejector, but account for it in initial conditions which must be calculated before trajectory calculations can begin.

A shortcoming of previously developed methods is the large computer time necessary to simulate the separation trajectories of aircraft stores. A third purpose for undertaking this study is to write a FORTRAN computer program which will require reasonable computer execution time to simulate the trajectories of ejected stores.

Finally, it is expected that the three-degree-of-freedom store separation prediction method will serve as a precursor to a six-degree-of-freedom method.

Approach

The method used to calculate separation trajectories is straightforward. Interference normal forces and pitching moment coefficients on the ejected store are determined using portions of Fernandes' subsonic interference loading program (Ref 3). Predetermined free-air normal force and pitching moment coefficients, obtained either by experiment

or any suitable theory, are then added to the interference loads. This sum, along with a predetermined axial force coefficient which remains constant throughout the trajectory, constitutes the total aerodynamic loading on the store. Next, normal force and pitching moment coefficients due to the store ejector system, when operating, are determined. Finally the pitching moment coefficient due to damping is calculated using a predetermined, from experiment or theory, pitch damping coefficient. All force and moment coefficients are then summed and a new position is determined by integrating the three-degree-of-freedom equations of motion. The process is repeated until clearance from the parent aircraft is assured.

II. Discussion of Loads on the Store

Interference Loads

Interference pitching moment and normal force coefficients are calculated using portions of the F. Dan Fernandes subsonic interference loading program (Ref 3). The calculation of the interference flow field by this method entails a linear theory of source, vortex, and doublet distributions. The aircraft wing, pylon, inlet and fuselage nose are modeled using various combinations of these distributions, the strengths of which are calculated by satisfying boundary conditions (no flow normal to the body surface) at various control points on the body. Disturbance velocities are then calculated over the length of the store as functions of these strengths and distances to the field point under consideration. From these disturbance velocities an interference angle-of-attack field can be determined. Interference forces and moments are then calculated by integrating the effects of this variable interference angle-of-attack field over the length of the store using predetermined (by experiment or theory provided by Fernandes) free-air body loading coefficients per unit angle-of-attack per unit length. Concurrently, the interference static pressure field over the length of the store is calculated and then integrated to yield the loading due to buoyancy on the store (Ref 3:5, E-1). Compressibility effects are included by applying the Prandtl-Glauert rule (Ref 3:A-1). Details on the interference

loading method are given by Fernandes (Ref 3).

Although Fernandes' program calculates five interference force and moment coefficients (normal force, side force, pitching moment, rolling moment, and yawing moment coefficients), the present method uses only two (pitching moment and normal force coefficients) because it is a three-degree-of-freedom analysis only. Interference axial force coefficient is not calculated by the Fernandes method and so this interference force is not accounted for in the present method.

Free-Air Loads

The calculation of total static aerodynamic loads on the store is completed with the addition of free-air loads to those interference loads determined by the Fernandes method. Free-air normal force and pitching moment coefficients are not calculated by the present method and, therefore, must be obtained before using it, usually as functions of store angle of attack and store Mach number. The free-air axial force coefficient must also be obtained before using the present method and is assumed constant throughout the trajectory simulation. Data may be obtained from experimental sources (as was done for the sample case considered in this report--see Chapter V) or from any suitable analytical method, such as USAF DATCOM (Ref 10, Sec 4).

Ejector Loads

Calculation of ejector normal forces and pitching moments is quite similar to the method used by Christopher and Carleton (Ref 2:32-33). Modifications were necessary to allow ejector force curves either as a function of ejector foot distance or as a function of time. In addition calculation of ejector normal force and pitching moment coefficients are made to permit comparisons of those ejector coefficients with corresponding interference and free-air coefficients.

The present method requires the ejector force-distance or force-time curves to be in the form of a fifth degree polynomial, the same form used by Christopher and Carleton (Ref 2:32). Two such curves are allowed to accommodate a two-point ejector system. In addition, the distance away from the center-of-gravity of the store at which each ejector is assumed to act must be known to calculate ejector moments on the store.

Pitching Moment Due to Damping

To account for the change in pitching moment due to aerodynamic damping, a pitch damping coefficient, required by the present method, must be known. According to Christopher and Carleton, the consideration of pitching moment due to aerodynamic damping is usually a second order effect, so any reasonable estimate for pitch damping coefficient, C_{mq}, should satisfy the requirements of the present method. Should the store exhibit large oscillatory motions,

however, this effect could become significant in which case consideration should be given to obtaining experimental values for C_{mq} or running trajectory sensitivity studies varying possible values for C_{mq} in order to determine its significance on the trajectory of the store under study (Ref 2:9).

The actual calculation of pitching moment coefficient due to aerodynamic damping is a simple one once C_{mq}, $dC_m/d(qb/2\ V_{store})$, is known:

$$C_{m_{DAMP}} = C_{mq} \cdot qb/2\ V_{store} \tag{1}$$

where

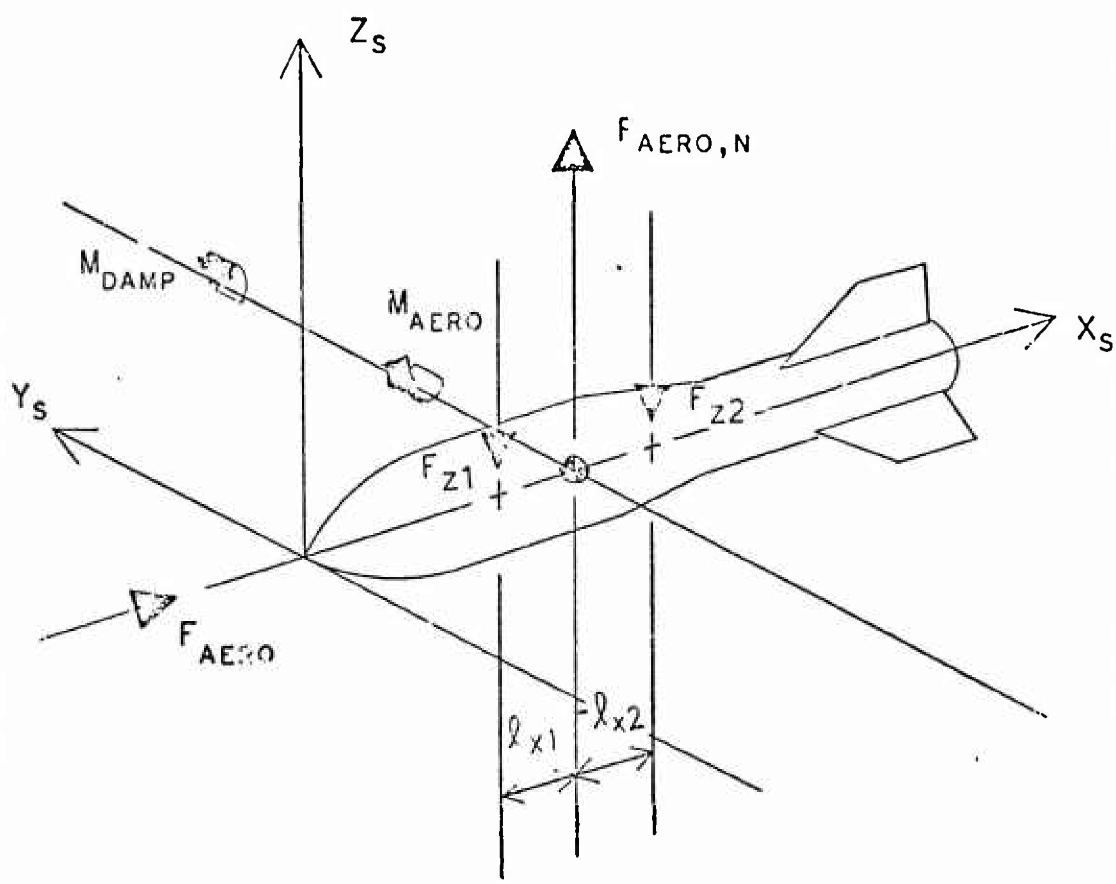
q = store pitch rate

b = store reference length

V_{store} = absolute store total velocity.

Total Loads on the Store

The total normal force load on the store is given by the sum of the loads due to interference, free-air, and ejector systems. The total axial force load on the store is computed using the predetermined axial force coefficient. The total pitching moment on the store is simply the sum of the moments due to interference, free-air, ejector system, and aerodynamic damping. These loads are illustrated in Fig. 1, in the coordinate system fixed in the ejected store.



WHERE

$F_{AERO,N}$ = sum of interference and free-air aerodynamic forces in the normal direction

$F_{AERO,A}$ = free-air aerodynamic force in the axial direction

F_{z1} = force due to ejector one

F_{z2} = force due to ejector tw

M_{AERO} = pitching moment due to interference and free-air aerodynamic loads

M_{DAMP} = pitching moment due to damping

Fig. 1. Forces and Moments on the Store in the Store Axis System.

III. Integration of Forces and Moments

Equations of Motion

The form of the three-degree-of-freedom equations of motion presented in this chapter was taken from Goodwin, Nielsen, and Dillenius (Ref 7:78-84). In place of the Goodwin method for calculating forces and moments on the store, however, the calculation of forces and moments by the present method, including free-air loading, interference loading, aerodynamic damping, and ejector loading, is used.

The inertial frame (ξ,η) for this treatment is fixed with the aircraft, hence the flight conditions must be non-accelerating. The aircraft, therefore, is assumed to fly at a constant flight path angle, γ_B, free stream velocity, V_∞, and angle of attack, α_B. Figure 2 illustrates this inertial coordinate system and the initial orientation of the store in it.

The longitudinal equations of motion in this coordinate system are:

$$m_s \ddot{\xi} = F_\xi \tag{2}$$

$$m_s \ddot{\eta} = F_\eta \tag{3}$$

$$m_s k^2 \ddot{\theta} = M_\theta \tag{4}$$

Now the forces on the store in the ξ-direction and η-direction, F_ξ and F_η, can be found by properly resolving

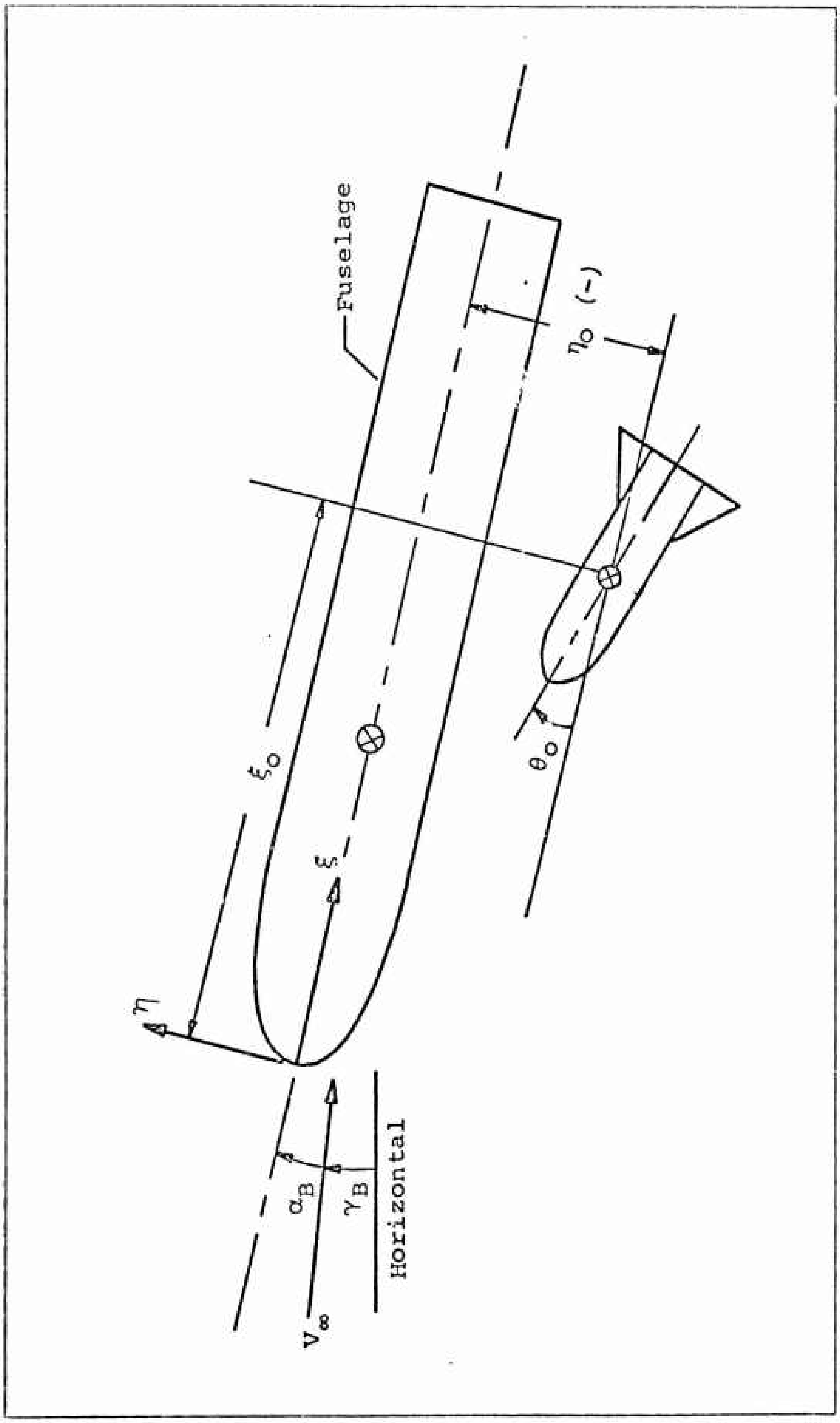


Fig. 2. Inertial Coordinate System Used for Trajector Calculations (taken from Ref 7).

forces along the store axis system into the inertial frame. The force normal to the store is simply

$$F_N = F_{int} + F_{fa} + F_{z1} + F_{z2} \tag{5}$$

The axial force on the store is given by

$$F_A = C_A \frac{1}{2} \rho_\infty V^2_{store} S_{ref} \tag{6}$$

The resolved forces are, then

$$F_\xi = F_N \sin\theta + F_A \cos(\alpha_B+\gamma_B-\gamma_S) + m_s g \sin(\alpha_B+\gamma_B) \tag{7}$$

$$F_\eta = F_N \cos\theta + F_A \sin(\alpha_B+\gamma_B-\gamma_S) - m_s g \cos(\alpha_B+\gamma_B) \tag{8}$$

where γ_S is the flight path angle of the store, which is different from γ_B if wind tunnel captive trajectory tests are to be simulated (Ref 7:84-85).

Noting that $C_N = F_N/(\frac{1}{2} \rho_\infty V^2_{store} S_{ref})$ and substituting Eqs (7) and (8) into Eqs (2) and (3), the first two equations of motion become

$$\ddot{\xi} = \frac{1}{2} \rho_\infty V^2_{store} (S_{ref}/m_s)[C_N \sin\theta + C_A \cos(\alpha_B+\gamma_B-\gamma_S)] + g \sin(\alpha_B+\gamma_B) \tag{9}$$

$$\ddot{\eta} = \frac{1}{2} \rho_\infty V^2_{store} (S_{ref}/m_s)[C_N \cos\theta + C_A \sin(\alpha_B+\gamma_B-\gamma_S)] - g \cos(\alpha_B+\gamma_B) \tag{10}$$

Substitution of $C_m = M_\theta/(\frac{1}{2} \rho_\infty V^2_{store} S_{ref} b)$ into Eq (9) yields the third longitudinal equation of motion

$$\ddot{\theta} = \frac{1}{2}\, \rho_\infty V^2_{store}(S_{ref} b / m_s k^2) C_m \qquad (11)$$

where C_m is the sum of the interference, free-air, ejector one, ejector two, and pitch damping moment coefficients. Equations (9), (10), and (11) are, except for slight changes in notation, exactly those equations derived by Goodwin, Nielsen, and Dillenius (Ref 7:79-80).

Integration Techniques

Equations (9), (10), and (11) must be integrated in order to calculate new store positions as well as angular and linear velocities and accelerations of the store at each time of interest. The method used for integration is a standard fourth-order predictor-corrector technique, utilizing a Runge-Kutta scheme to calculate intermediate steps, and was taken from Goodwin, et al. The method is introduced in their three-degree-of-freedom report (Ref 6:26) and explained in detail in their six-degree-of-freedom report (Ref 9:139-142, 219-221).

Actual integration of the equations of motion may be started at any desired time, provided the correct initial conditions, store position and linear and angular velocities, are known. The forces and moments are calculated using methods outlined in Chapter II, then a new position is found by integrating Eqs (9), (10), and (11) into which have been substituted the calculated values for C_m and C_N. The process is then repeated until clearance is assured.

IV. Computer Program

Computer Memory and Execution Time Requirements

A FORTRAN computer program was developed for the present method. It is operational on the CDC 6600 computer with the SCOPE 3.4 operating system and library tape and requires about 60000 octal storage registers for loading. Execution time varies greatly, depending on how much detail is taken in describing the geometry of the parent aircraft, how many store sections are considered for computing interference loading, the time step size chosen for integration of the equations of motion, and the computational mode desired for this integration. Execution time for the trajectory simulations of the M-117 bomb from an F-4E are listed in Chapter V and discussion of computational modes in Appendix A.

Overview of Computer Program

The bulk of the computer program consists of twenty-six subroutines taken from Fernandes (Ref 5), all necessary in computing the interference loading on the aircraft stores. In addition, the predictor-corrector subroutine necessary for integration of the equations of motion, subroutine ADAMS, was taken from Goodwin (Ref 6).

The user of the computer program must supply his own subroutine, FREAIR, whose purpose is to calculate the free-air pitching moment and normal force coefficients on the store, given the store angle of attack and Mach number.

The main program whose primary purpose is to organize calculations by calling necessary subroutines, calls two other subprograms, TRREAD and TRAJEC. The purpose of subroutine TRREAD is to read in values of store geometry, store mass characteristics, ejector characteristics, pitch damping coefficient, axial force coefficient, and aircraft flight conditions necessary for separation calculations. This subroutine also initiates values of the dependent variables, store position and pitch angle, and linear and angular velocities required for integration of the equations of motion.

The purpose of subroutine TRAJEC is to accept store position and interference loads, calculate free-air loads, ejector loads, and pitch damping, sum all loads and output them. It then integrates the equations of motion and returns a new store position and orientation to the main program.

A user's guide for the computer program is presented in Appendix B and a listing of the program, with the exception of those 26 subroutines taken from Fernandes (Ref 5), is provided in Appendix C. A few minor changes to those Fernandes subroutines, necessary to pass interference coefficients to the main program and to avoid extraneous output, are also listed in Appendix C. The computer codes for the Fernandes subroutines themselves are available through COSMIC (Computer Software Management and Information Center). Requests should be directed to: COSMIC, University of Georgia 30601.

V. Results and Discussions

Simulated M-117 Trajectories

Sample trajectories were calculated using the present method and the Goodwin method (Ref 8) for the M-117 all-purpose bomb ejected from the F-4E aircraft on the 81.50 (inboard) pylon. A sketch of the M-117 bomb is shown in Fig. 3 and its aerodynamic, mass, and geometric characteristics used in theoretical calculations are listed in Table I (Ref 10:25,100).

Table I

Full-Scale M-117 Parameters

Parameter Name	Parameter Value
m_s, slugs	25.45
X_{CG}, feet	2.333
X_L, feet	-0.3417
$Z_{E_{max}}$, feet	0.275
S_{ref}, sq ft	1.395
b, ft	1.333
C_A	0.1
I_{YY}, slugs-sq ft	50.0
C_{mq}, per rad	-70.0

The M-117 bomb was chosen for a sample calculation because experimental data on free-air stability characteristics (Ref 13:25) were available and, under certain flight

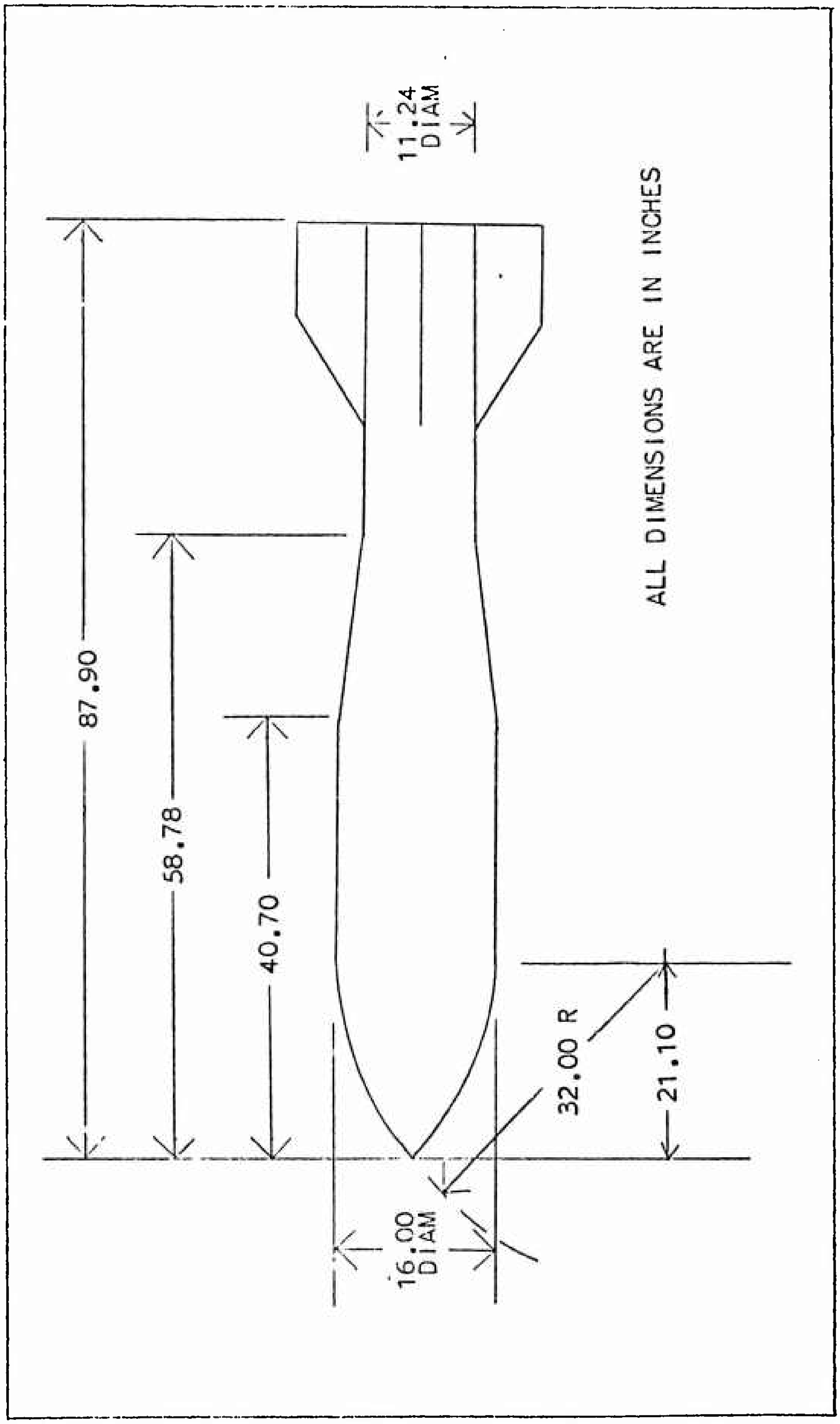


Fig. 3. Sketch of the M-117 All-Purpose Bomb.

conditions and ejector loads, the M-117 exhibited small lateral (yaw angle and y-direction) excursions.

Experimental trajectories were taken from an AEDC wind tunnel report whose author investigated the effects of wing leading-edge slats on the separation characteristics of various stores as carried on the F-4E' (Ref 11). That same wind tunnel investigation modeled separation trajectories from the F-4E aircraft without leading edge modifications and it is those baseline trajectories to which the theoretical results are compared.

The ejector force-distance curve used in the present method was taken from the same AEDC wind tunnel report and is shown in Fig. 4.

Comparison of Store Trajectories

Figures 5, 6, 7 and 8 exhibit X and Z coordinates, relative to carriage position, of the center of gravity of the store, as well as the absolute pitch angle of the store as seen in the fuselage wind-axis system. Results from experiment and both the present method as well as the method due to Dillenius, et al. (Ref 8) are shown.

As illustrated in Fig. 5 both methods predicted the experimental results remarkably well for the low speed, moderate angle-of-attack case (Mach = 0.332, α = 7.40), with the present method doing slightly better in position prediction and the previously developed method predicting pitch angle excursions more accurately. In Fig. 6, however, while linear

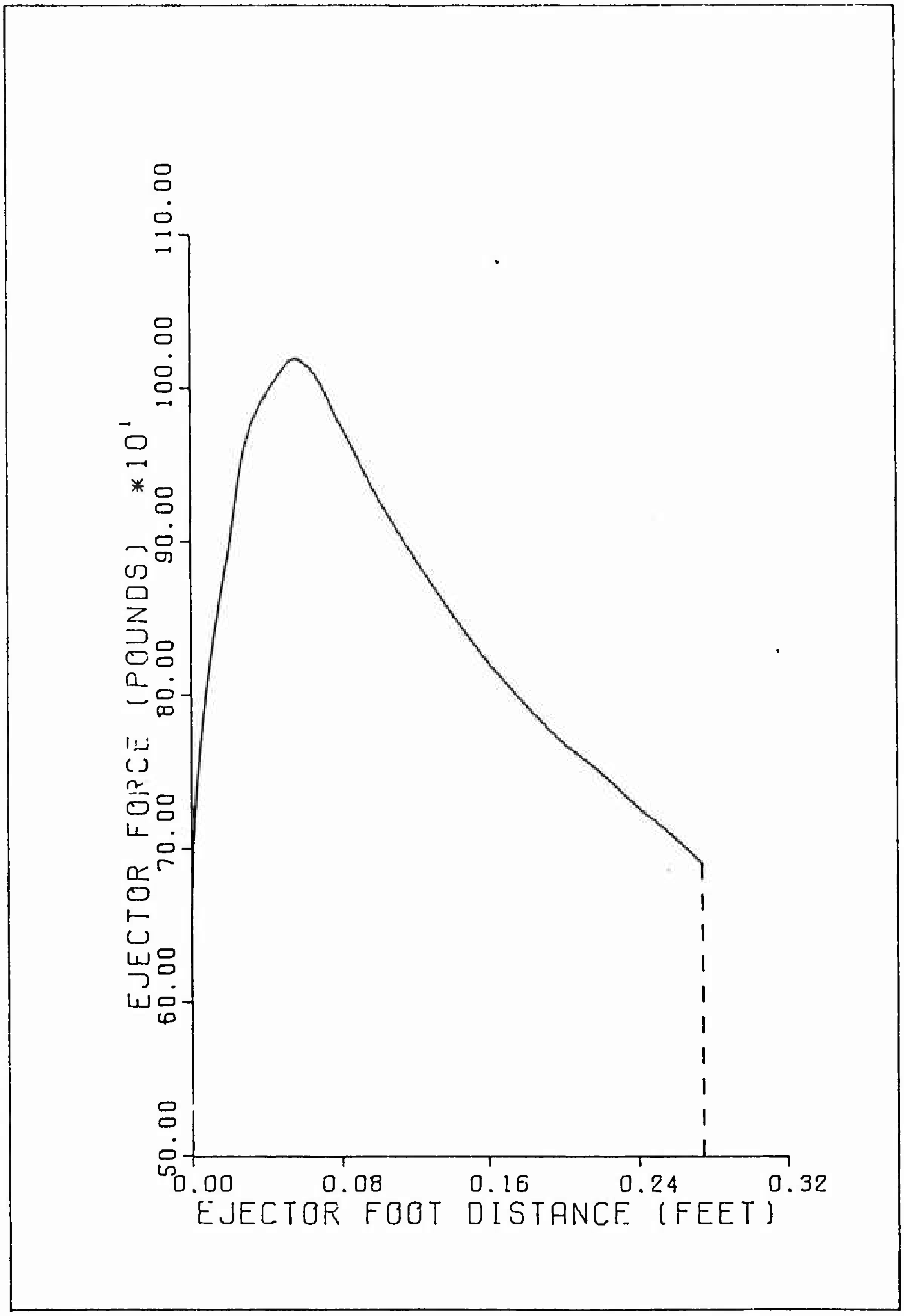


Fig. 4. Ejector-Force Function for the M-117 Bomb.

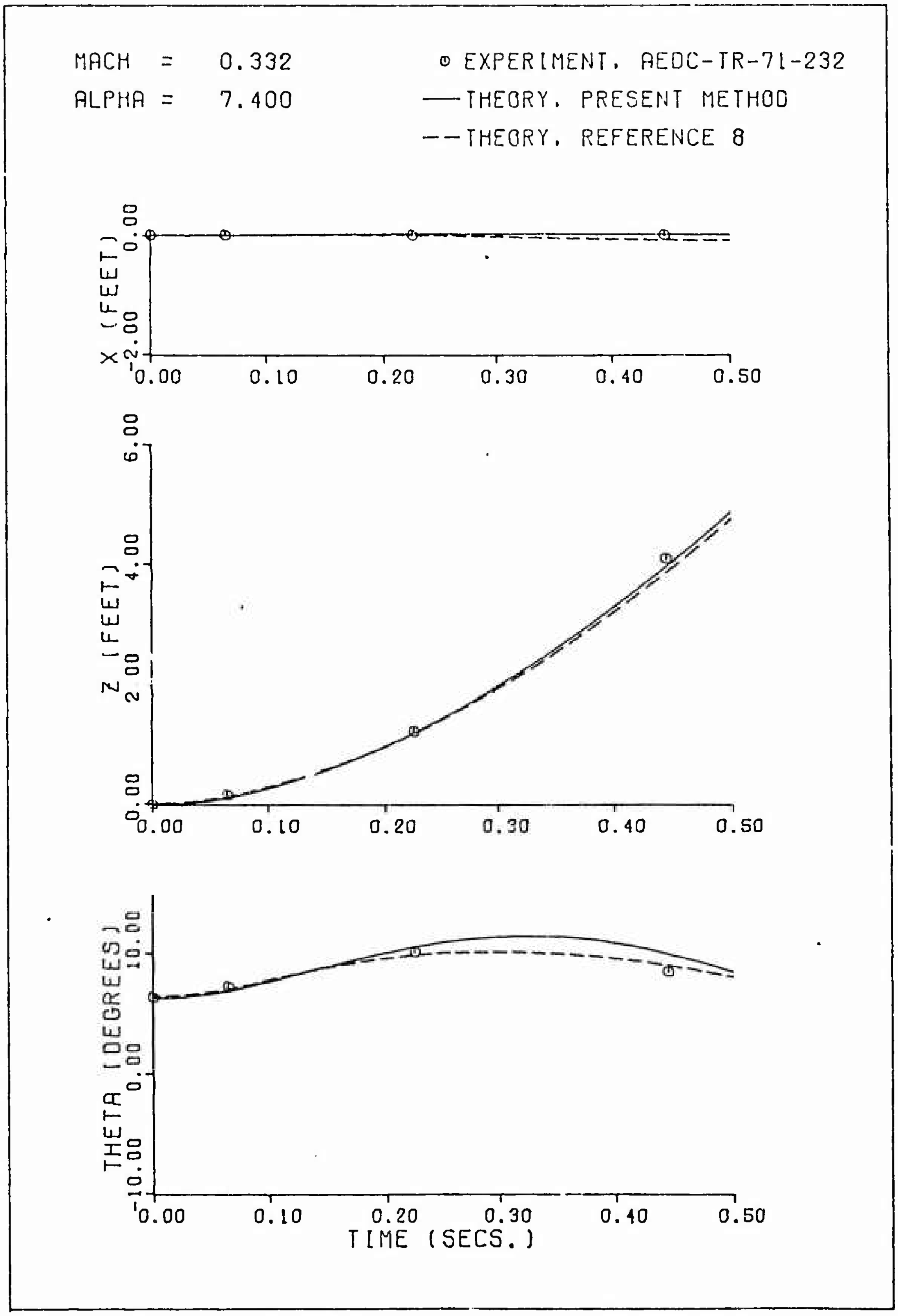


Fig. 5. Simulated Separation Characteristics of the M-117 Bomb.

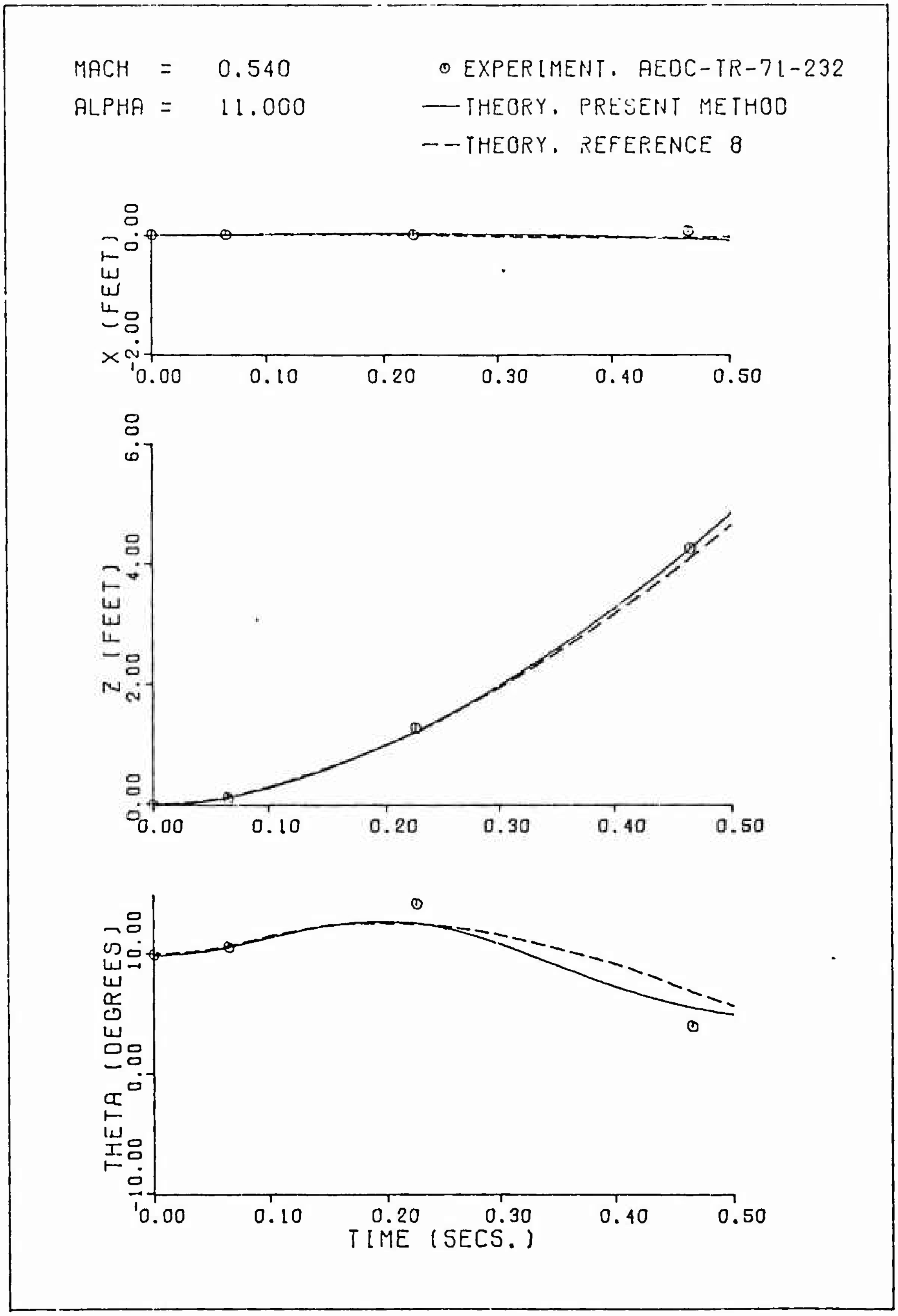


Fig. 6. Simulated Separation Characteristics of the M-117 Bomb.

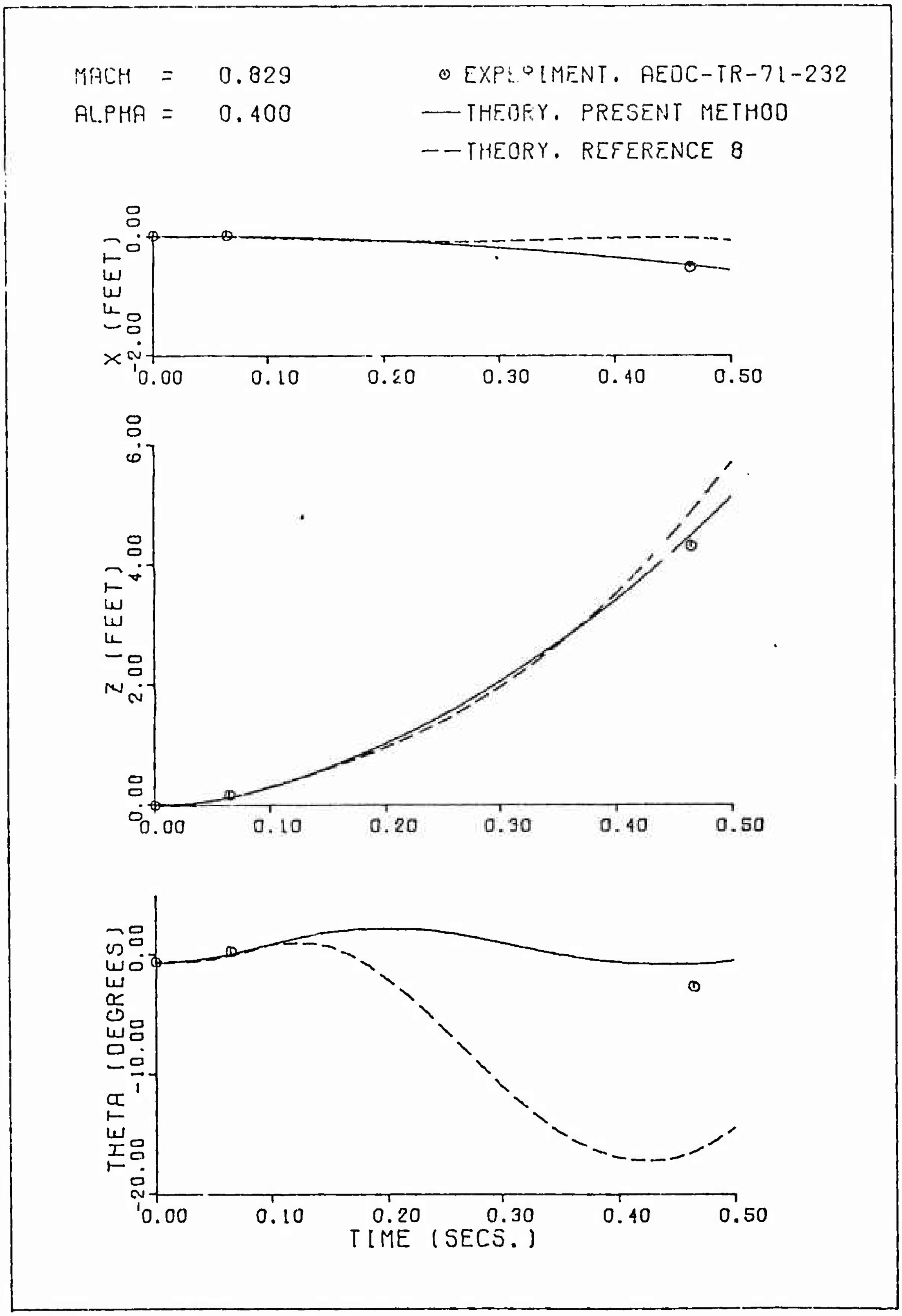


Fig. 7. Simulated Separation Characteristics of the M-117 Bomb.

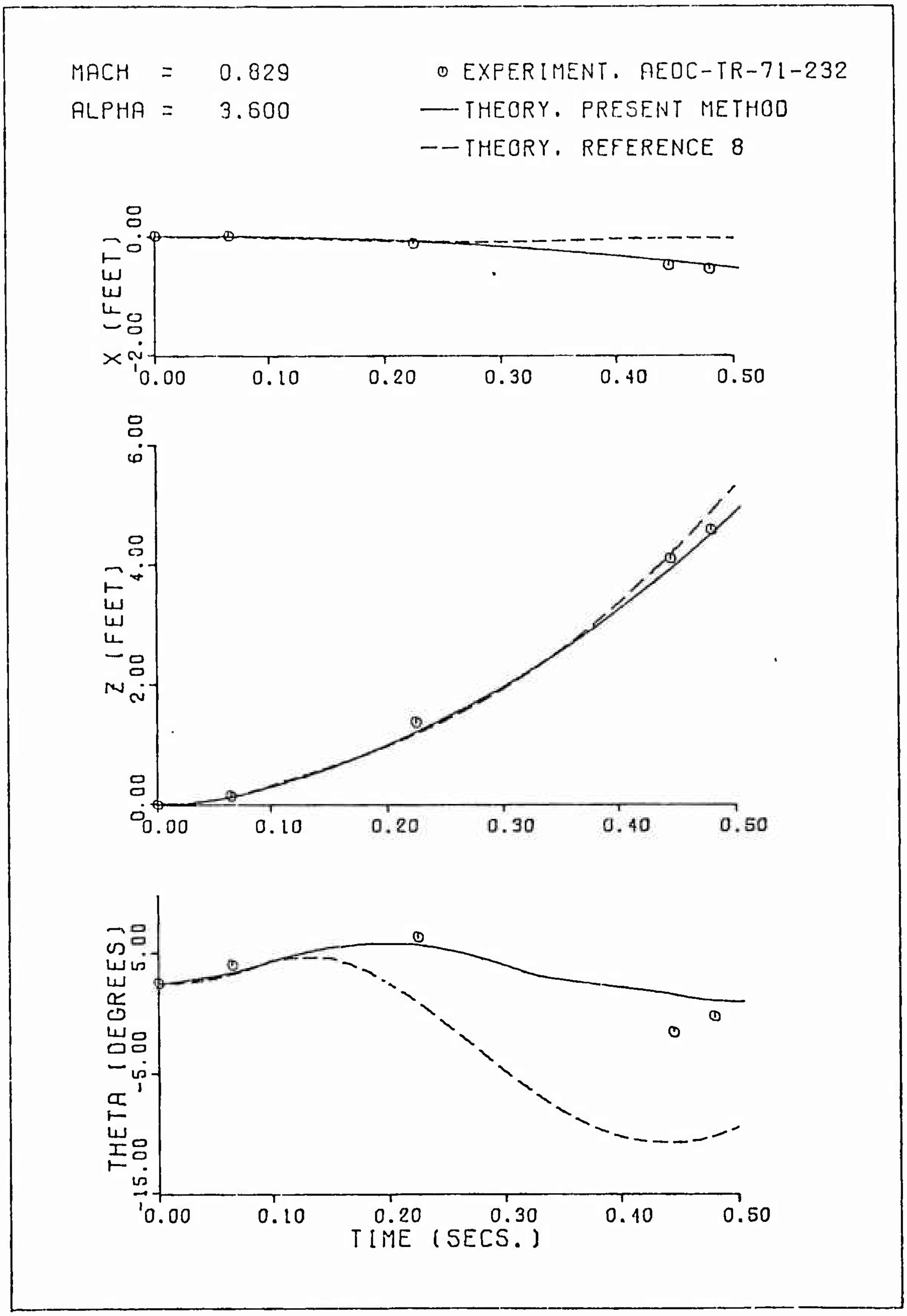


Fig. 8. Simulated Separation Characteristics of the M-117 Bomb.

distance vs. time curves are again estimated quite well, the pitch angle calculation is not as close to experiment as in the previous case. It is difficult to conjecture which method predicts pitch angle better, since both indicate the damped sinusoidal pitch angle profile common to stable stores, but the trajectory due to the present method has a shorter period of pitch oscillation than does the trajectory due to the Goodwin method (Ref 8).

For the high speed case (Mach = 0.829), Figs. 7 and 8 show interesting results. While the present method again predicts linear travel quite well and pitching angle reasonably well, the method obtained from Ref 8 shows a definite deviation from experiment slightly after ejector time cut-off (about 0.08 seconds). A Mach number equal to 0.829 results, more than likely, in a supercritical flow-field situation, thus violating a basic assumption of the method (Ref 8), that conditions modeled are to be at subcritical speeds only, thereby rendering the results calculated at the high speeds invalid.

The application of the present method to relatively high Mach numbers (0.829) might also be construed as a violation of the subcritical speed restriction placed on the Fernandes method. While technically this is true, there is no such restriction on the other sources of store loading, so the present method can be pushed past the normal critical speed (about Mach = 0.7 to 0.8) with relative safety provided the free-air loading is known with some confidence.

Reasons for the excellent agreement of the present method with experiment are many, one of which is certainly the acceptable results the Fernandes method for calculating interference forces and moments seems to produce (Ref 3:13-21). Good results for total aerodynamic loading is assured by the fact that the experimental free-air data was available to add to the analytically predicted interference loads.

Store loading due to ejector forces and due to aerodynamic damping are modeled in the present work exactly as they are in the AEDC tunnel tests and as a result should introduce no error into calculations of store trajectories. In the case of the ejector forces at low speeds, this effect can be quite significant because, when operating, the ejector forces tend to overwhelm the aerodynamic forces. Figure 9 illustrates this point for the low speed (Mach = 0.332) case. At higher aircraft speeds, however, the aerodynamic forces are greater and do not, in general, dominate the ejector forces, as indicated in Fig. 10 for the Mach = 0.829 case.

A final reason for satisfactory results is the fact that the M-117 is a very dense store. Dense stores have higher inertial-to-aerodynamic-loads ratios than do lighter weight stores of the same general shape and so are not "blown around" as easily as their lighter weight counterparts.

Comparison of Computer Execution Time

The execution times required by the computer program utilizing the present method can be directly compared to that

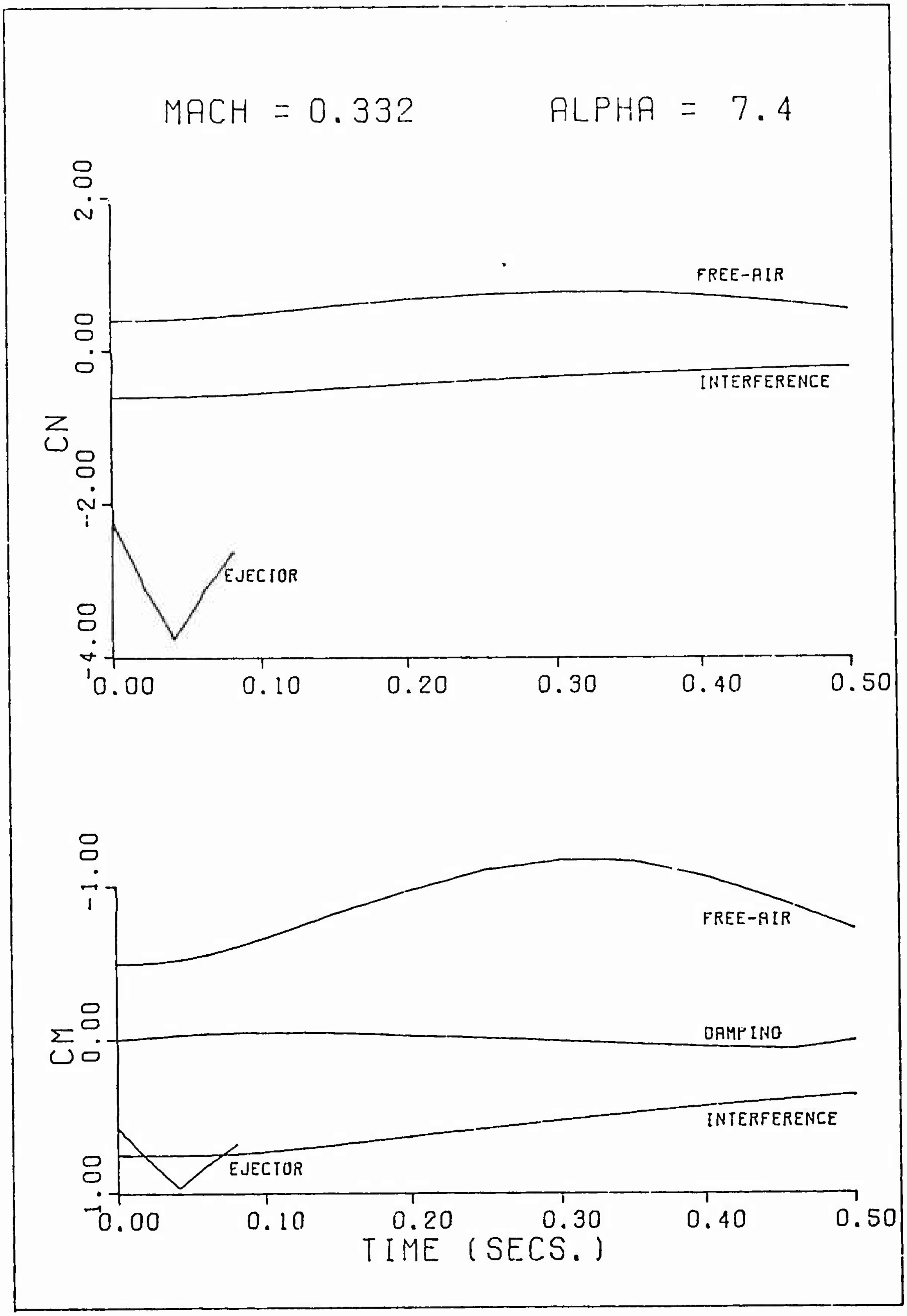


Fig. 9. Comparison of Loads on the M-117 Bomb for the Low Speed Case.

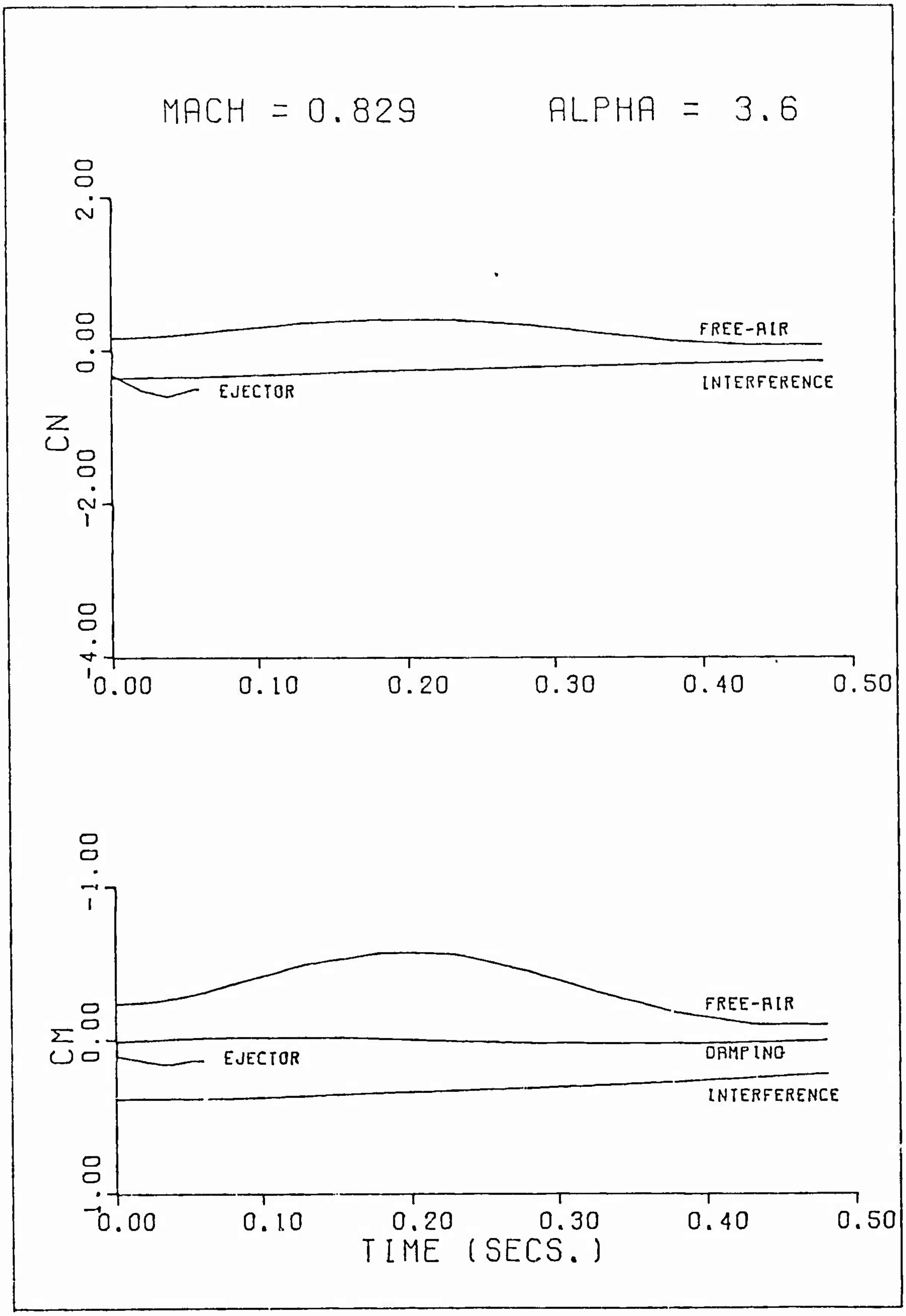


Fig. 10. Comparison of Loads on the M-117 Bomb for the High Speed Case.

of the computer program written by Goodwin and Dillenius (Ref 9). Two different execution times are listed in Table II for the present method, illustrating the two computational modes available in its corresponding computer program. These

Table II

Comparison of CDC 6600 Computer Execution Time

			Computer Execution Time (secs)		
			Present Method		Ref 8 Method
Case	Mach	Alpha	KSTABLE=0	KSTABLE=1	
1	0.332	7.4	98	30	205
2	0.540	11.0	98	67	204
3	0.829	0.4	142	46	209
4	0.829	3.6	142	43	210

computational modes, KSTABLE=0 and KSTABLE=1, yield essentially the same store trajectories and are explained in detail in Appendix A. Examination of Table II reveals that the present method yields some dramatic savings in computer execution time, while losing no noticeable accuracy in trajectory simulation at low and moderate speeds, and actually extending the speed regimes for reasonably accurate trajectory simulation to higher subsonic speeds than those allowed by the Goodwin method (Ref 8).

Both computer programs are operational on the CDC 6600 computer with the SCOPE 3.4 operating system and library

tape. The program due to Goodwin (Ref 9), which was modified to restrict movement to the pitch plane only, requires about 114000 octal storage registers for loading. The program written using the present method requires about 60000 octal store registers for loading.

VI. Conclusions and Recommendations

Conclusions

Results from the present prediction method compared well with experimental results for store trajectories which exhibit minimal lateral characteristics. Although previously developed trajectory prediction techniques (Refs 7 and 8) and the method used in the present work to calculate interference loads are limited to the subcritical speed regime, the present method may be used with some confidence past the subcritical cut-off because experimental data used to calculate free-air loads on the store is usually available for supercritical speeds. In addition, the method used to calculate the loads due to the ejector system is not limited to any aircraft speed regime, so the method used to calculate ejector loads may also be used supercritically.

A substantial improvement in computer execution time was realized with the present method over the method due to Goodwin, Dillenius, and Nielsen (Ref 8). This savings was even greater for the KSTABLE=1 mode, discussed in Appendix A, although all store trajectory simulations may not be suitable to allow the use of that time-saving feature.

Regardless of how well the present method predicts the three-degree-of-freedom trajectory of an aircraft store, its engineering practicality is limited because it is a three, not a six, degree-of-freedom analysis. Should the store trajectory under investigation not be suited to a pitch-plane

analysis, or should experimental store static stability data not be available, the six-degree-of-freedom analysis due to Goodwin, Dillenius, and Nielsen (Ref 8) should be used.

Recommendations

As alluded to above, the first obvious extension of the present method would be one to accommodate the other three degrees of freedom (side force, yawing moment, and rolling moment). While this sounds straightforward, consideration of all six degrees of freedom compounds problems immensely and should not be viewed lightly. Goodwin, Dillenius, and Nielsen (Ref 8) have completed this task using their theory for calculating store loading, so much of their work could again be utilized. However, as yet, the Fernandes method does not allow consideration of a yawed store so considerable modification to his method must be completed.

In addition, improvement to the Fernandes method itself could be attempted. Of particular interest would be to allow some consideration of wing-body interference, addition of an arbitrarily shaped representation of the fuselage, and the addition of other bodies to account for store-to-store interference. A method similar to Goodwin, et al. (Ref 7:20-22) would be the simplest to employ in order to get a first order effect for wing-fuselage and store-to-store interference. In that method, an induced camber on the wing is calculated to cancel the effect of the fuselage changing the boundary

conditions on the wing when the two independent solutions, wing and body, are superimposed.

Thirdly, the rack could be modeled, possibly as a distribution of axisymmetric sources (Ref 8:20) or, as suggested by Goodwin, et al. (Ref 8:20), a combination distribution of axisymmetric sources to account for rack thickness and a small system of vortices to account for the short wing-like stubs which normally protrude from most bomb racks.

Another area which typically gets little consideration is the elastic effect on the rack and, consequently, the net force felt by the store due to the extremely high ejector forces common to most store-ejector systems.

Finally, consideration should be made to the development of a supersonic three or six-degree-of-freedom trajectory program. Fernandes (Ref 4) has written a companion program to his subsonic interference loading program which will compute interference loads on a store in the flow field of an aircraft flying at supersonic speeds. His supersonic method could be incorporated into a new technique in a manner quite similar to that developed here.

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Appendix A

Computational Modes Available in the Computer Program

A standard fourth-order predictor-corrector technique was used to integrate the equations of motion. At the onset, and at each subsequent change in step size of the integration routine, Runge-Kutta calculations are made to determine intermediate values of the dependent variables. Large computer execution times were introduced because at each major and each intermediate time step all forces and moments must be calculated according to the methods outlined in Chapter II. Calculation of interference forces and moments, as might be expected, required the most amount of time, on the order of two seconds per store position for a typical fighter-bomber. To alleviate this problem a parameter, KSTABLE, may be input with the value of 1. This will suppress the calculation of interference loadings at each intermediate time step, thereby reducing computational time significantly. The resultant savings in computational time for the trajectory simulation examined in this study is listed in Table II of Chapter V.

Some care should be exercised in choosing which computational mode, the KSTABLE=0 mode or the KSTABLE=1 mode, is used. In the example of the M-117 bomb trajectory simulation, interference loads did not change much for intermediate time steps. This was probably due to the high weight and

good stability of the bomb causing small pitch oscillations at these intermediate time steps. This may not be the case, however, for unstable or lighter weight stores, so trajectory sensitivity studies should be run, using both computational modes, at extreme Mach numbers and angles of attack. A comparison of trajectories calculated from each mode should enable the determination of the suitability of the time-saving KSTABLE=1 mode for the aircraft/store under consideration.

Appendix B

User's Guide to the Computer Program

Most of the inputs to the computer program describe the aircraft geometry, store loading, coefficients, and parameters to determine the number of flow singularities used to represent the interference flow field as seen by the store. These items are input exactly as described by Fernandes (Ref 3:26-47) and will not be repeated here. The only change from the original Fernandes inputs is his control parameter for run stacking, IGO. This final Fernandes input is eliminated altogether for the present computer program.

The remaining inputs required by the present computer program will now be presented.

CARD 1 (after Fernandes inputs) consists of four control parameters input in format 4I5.

KSTABLE is the computational mode parameter discussed in Appendix A. KSTABLE=0 causes calculation of interference forces at all time steps; KSTABLE=1 causes calculation of interference forces at major time steps only.

NEJECT is the ejector curve control parameter. NJECT=0 implies the ejector curve to be input is Force-distance; NEJECT=1 implies Force-time.

NGAM	is the index controlling flight path angle. NGAM=0 causes the trajectory simulation to be free-air; NGAM=1 causes a wind tunnel captive-store simulation.
NCNMAX	is the index indicating the maximum number of major time steps allowed during integration.

CARD 2 contains four store parameters input in 4F10.5 format.

SMASS	is store mass. (slugs)
RGYRAY	is store radius of gyration about y-axis. (feet)
XCG	is the store center of gravity measured behind store nose. (feet)
SRMAX	is store maximum radius. (feet)

CARD 3 contains these four parameters input in 4E12.4 format.

VINF	is aircraft flight velocity. (feet per second)
GAMF	is aircraft flight path angle. (degrees)
RHO	is air density at simulated altitude. (slugs per cubic foot)
G	is acceleration due to gravity. (feet per second per second)

CARD 4 requires these four inputs in format 4E12.4.

CA	is the store axial force coefficient, assumed constant throughout the simulation.

VZERO is the store initial translational motion. Direction is normal to store longitudinal axis. (feet per second)

VAR(6) is the store initial pitching velocity about y-axis. Positive is nose up. (radians per second).

Note that VZERO and VAR(6) should be input as zero unless ejector simulation is <u>not</u> desired.

<u>CARD 5</u> contains a one-dimensional array of order six whose input is 6E12.4.

C(1), C(2), ... C(6) are the coefficients, low-to-high order, of the fifth order polynomial curve fit of the ejector Force-time or Force-distance curves of ejector one.

<u>CARD 6</u> also contains a one-dimensional array of order six whose input is 6E12.4.

D(1), D(2), ... D(6) are the coefficients, low-to-high order, of the fifth order polynomial curve fit of the ejector Force-time or Force-distance curves of ejector two.

<u>CARD 7</u> consists of six parameters input in format 6F10.5.

CMQ is the pitch damping coefficient. (per radian)

XL1 is the ejector one piston location relative to the store center of gravity, positive forward of store center of gravity. (feet)

XL2 is the ejector two piston location relative to the store center of gravity, positive forward of store center of gravity. (feet)

EJEND1 is the ejector one cut-off argument. (feet or seconds, depending on NEJECT)

EJEND2 is the ejector two cut-off argument. (feet or seconds, depending on NEJECT)

EJANGL is the angle from the vertical in the aircraft y-z plane, at which each ejector is assumed to act. (degrees)

Note that in this pitch-plane analysis only that component of the ejector force curve in the aircraft z-direction is considered.

CARD 8 contains four time parameters input in format 4E12.4.

DTIME is the initial integration interval. (seconds)

TIMEI is the initial time of trajectory. (seconds)

TIMEF is the final time of trajectory. (seconds)

DTIME2 is the integration interval after both ejectors have stopped. (seconds)

If no ejector is present input DTIME2 equal to DTIME. If at least one ejector is present, DTIME on the order of 0.02 seconds and DTIME2 around 0.05 seconds have proved to be satisfactory. A TIMEF of 0.5 to 0.7 seconds is satisfactory for all but unusual trajectories.

CARDS 9 and 10 contain six inputs necessary to start any trajectory whose initial time is not equal to zero. These items are output from the computer program and are input in 5E14.7 format.

VAR(1) is the x-location of the store center of gravity in the fuselage coordinate system. (feet)

VAR(2) is the z-location of the store center of gravity in the fuselage coordinate system. (feet)

VAR(3) is the store pitch angle about the fuselage y-axis. Positive is nose up. (degrees)

VAR(4) is the x-velocity of the store center of gravity in the fuselage coordinate system. (feet per second)

VAR(5) is the z-velocity of the store center of gravity in the fuselage coordinate system. (feet per second)

VAR(6) is the store pitch rate about the fuselage y-axis. Positive is nose up. (radians per second)

Appendix C

Computer Program Listing

Explanation of Listed Programs

In this appendix are listed the main program and all subroutines with the exception of those 26 subroutines taken from Fernandes (Ref 5). Subroutine ADAMS was taken directly from Goodwin (Ref 6:76). The subroutine FREAIR, listed here as an example, was composed specifically for the M-117 bomb and, of course, will be different for other stores. Subroutine TBLNDC, available from the WPAFB computer library is called from the specific FREAIR listed in this appendix, and is included for completeness.

Changes to the Fernandes Subroutines

Changes were necessary to the Fernandes subroutines to pass the interference coefficients to the main program and to avoid extraneous output.

The Fernandes program has card identifiers, in columns 75 through 79, sequenced in intervals of 10. Cards listed below whose identifiers end in the number "0" are to replace those in the Fernandes subroutines with the same identifiers. All other cards are to be inserted into the Fernandes subroutines in the sequential order implied by their identifiers.

Subroutine INFLUN

```
      COMMON /TRAJ/                        NRUN,KSTOP,CNZP,CMZR        E  85
      IF(NRUN .EQ. 0)WRITE (6,80) ALFH,ALFH                            E 110
      IF(NRUN .EQ. 0)WRITE (6,90) ROLL                                 E 130
      IF(NRUN .EQ. 0)WRITE (6,110) X,CNZ,CNY,CMZ,CMY,CL,CNZP,CNYP,CMZP,C E 590
     1MYP                                                              E 595
```

Subroutine DISTURB

```
      COMMON /TRAJ/                        NRUN,KSTOP,CNI,CMI          D  85
      IF(NRUN .EQ. 0)WRITE (6,130) XM(L),YM(L),ZM(L),XT(L),ALFMH(L)    D 110
      IF(NRUN .EQ. 0)WRITE (6,140) IP,IA,IN,NK,FIN,DIA                 D 260
      IF(NRUN .EQ. 0)WRITE (6,150)                                     D 650
      IF(NRUN .NE. 0)RETURN                                            D 725
```

```
      PROGRAM DROPIT     74/74    OPT=0   TRACE                         FTN 4.1+P373        06/27/74

            PROGRAM DROPIT(INPUT,OUTPUT,PUNCH=65,TAPE5=INPUT,TAPE6=OUTPUT)
      C
      C
      C     PROGRAM DROPIT COMPUTES THE 3-DOF SEPARATION TRAJECTORIES OF
      C     AIRCRAFT STORES
      C
      C     INTERFERENCE LOADING COEFFICIENTS CALCULATED USING METHOD (AND
      C     SUBROUTINES) DUE TO F. DAN FERNANDES (SEE NASA-CR-112065-1)
      C
      C     INTEGRATION OF EQUATIONS OF MOTION TAKEN FROM GOODWIN, NIELSEN,
      C     AND DILLENIUS (SEE NEAR TR 30 AND AFFDL-TR-71-81)
      C
      C     CARDS IDENTIFIED IN COLUMNS 73-80 WITH "A XXX", WHERE "XXX" IS
      C     A THREE-DIGIT NUMBER, WERE TAKEN DIRECTLY FROM THE FERNANDES MAIN
      C     PROGRAM
      C
      C     CARDS IDENTIFIED IN COLUMNS 73-80 WITH "TRJAXXX" OR "TRJLXXX",
      C     WHERE "XXX" IS A THREE-DIGIT NUMBER, WERE TAKEN DIRECTLY FROM THE
      C     GOODWIN MAIN PROGRAM AND SUBROUTINES (SEE NEAR TR 30)
      C
      C
            COMMON /TRAJ/                         NRUN,KSTOP,CNI,CHI
            COMMON /GST/ RAD,PI,BETA,BM,IGO,BETA2,F5                          A 300
            COMMON /DICT/ XM(1),YM(1),ZM(1),XT(1),ALFMH(1)                    A 310
            DIMENSION ALFW(5)                                                 A 320
            DATA (RAD=0.0174533),(PI=3.14159),(NRUN=0),(IGO=3)                A 330
            KSTOP=0
            KODE=0
            WRITE (6,90)                                                      A 340
         10 CONTINUE                                                          A 350
            CALL TITLES (2,0,0)                                               A 360
            CALL TIMEX                                                        A 370
            READ (5,120) BM                                                   A 380
            BETA2=ABS (1.0-BM**2)                                             A 390
            BETA=SQRT(BETA2)                                                  A 400
            WRITE (6,100) BM,BETA                                             A 410
            IF (BM.EQ.1.0) GO TO 70                                           A 420
            CALL AIRCFT                                                       A 430
            CALL TIMEX                                                        A 440
         20 CONTINUE                                                          A 450
            IF (IGO.EQ.2) GO TO 30                                            A 460
            CALL TITLES (0,2,0)                                               A 470
            CALL STORE                                                        A 480
         30 READ(5,110)NTL
            CALL TITLES(0,0,2)
            READ(5,120)XM(1),YM(1),ZM(1),XT(1),ALFMH(1)
            READ(5,115)NALF,IH,IA,IW
            READ(5,120)ALFW(1)
            CALL TITLES(1,1,1)
            WRITE(6,130)BM
            IF(NRUN .EQ. 0)CALL TREAD(ALFW(1),KODE,KSTABLE)
         35 CALL WISTUP3(IH,IA,IW)
            IW=0
            CALL TIMEX
            CALL INFLUN(ALFW(1),ALFMH(1),XT(1),IH)
            CALL TIMEX
            CALL TRAJEC(BM,KSTABLE)
```

```
PROGRAM DROPIT      74/74    OPT=0   TRACE                    FTN 4.1+P373        08/27/74

              IF(KSTOP .EQ. 1)STOP
              NRUN=NRUN+1
              GO TO 35
        70    WRITE (6,150)                                                          A 710
        80    CALL EXIT                                                              A 720
        C                                                                            A 730
        C     -END STORED (MAIN PROGRAM)                                             A 740
        C                                                                            A 750
        C                                                                            A 760
        C                                                                            A 770
        90    FORMAT (1H1,59HTHIS PROGRAM PREDICTS AERO INTERFERENCE ON AIRCRAFT     A 780
             1 STORES,//,34HMETHOD FORMULATED AND PROGRAMMED BY F DAN FERNANDES)     A 790
        100   FORMAT (1H0,12HMACH NUMBER=,F6.3,5X,7HDELTA=,F7.4)                     A 800
        110   FORMAT (7I15)                                                          A 810
        120   FORMAT (7F10.4)                                                        A 820
        130   FORMAT (1H5,12HMACH NUMBER=,F6.3,5X,11HRESULTS FOR)                    A 830
        140   FORMAT (20X,10HEND OF RUN,5X,I2)                                       A 840
        150   FORMAT (1H1,23HINPUT ERROR, BH OR HALF)                                A 850
              END                                                                    A 860-
```

```
SUBROUTINE TRPEAD      74/74    OPT=0    TRACE                    FTN 4.1+P372        08/27/74

      SUBROUTINE TRREAD(DUMMY,KODE,NSTABLE)
C
C
C     CARDS IDENTIFIED IN COLUMNS 73-80 WITH "TRJAXXX", WHERE "XXX" IS
C     A THREE-DIGIT NUMBER, WERE TAKEN DIRECTLY THE [illegible] MAIN PROGRAM
C     AND SUBROUTINES (SEE [illegible] 33)
C
C
      COMMON /C1C/ YM(1),YM(1),ZM(1),XT(1),ALFMW(1)
      COMMON /[illegible]/ [illegible],YMOMIN,VINF,GAME,
     1[illegible],EJECT1,EJECT2,DTIME,
     2TIME1,[illegible],
     3[illegible],CBAR(6),
     4ANGATK,[illegible],RAD,[illegible],NGAM,NDEG,[illegible],FACTOR,ZINERT
      DIMENSION YSSS(1),ZSSD(1)
      DATA NSTP/1/
  415 FORMAT(5F12.4)                                                    TRJA 51
  416 FORMAT(/I4 )                                                      TRJA 64
  434 FORMAT(////1X,[illegible] FLIGHT CONDITIONS/15X,10HVELOCITY =,1PE1TRJA 98
     11.4,7 [illegible] ANGLE =,[illegible] DEG/15X,17HAIR TRJA 99
     2DENSITY =,[illegible] FT/15X,[illegible] MODEL:PATIOTRJA100
     3N =,1PE11.4,[illegible]                                           TRJA101
  435 FORMAT([illegible]EFFICIENT AT ZERO LIFT/15X,[illegible] =,1PE1TRJA102
     111.4/[illegible] INITIAL VELOCITY RELATIVE TO AIRCRAFT/15X,[illegible]TRJA103
     2[illegible],1PE11.4)                                              TRJA104
  438 FORMAT([illegible] USED IN FORCE AND MOMENT CALCUTRJA1.7
     1LATION/16X,11HAREA, S[illegible],10HLENGTH, FT/14X,1PE11.4,[illegible],1PE11.4TRJA108
     21 .                                                               TRJA109
 6658 FORMAT(5E14.7)                                                    TRJA [illegible]
C                                                                       TRJA653
C     INITIALIZE FOR TRAJECTORY CALCULATION                             TRJA654
C                                                                       TRJA655
 1105 PI=3.1415927                                                      TRJA656
      NCONTR=1
      IF(KODE .EQ. 1)GO TO 871
      READ(5,5)NSTABLE,NEJECT,NGAM,NONMAX
    5 FORMAT(8I5)
      WRITE(6,100)
  100 FORMAT(1H1, *THIS PAGE LISTS ALL INPUTS AND PARAMETERS NECESSARY
     1FOR TRAJECTORY SIMULATION*/,6X *THESE INPUTS ARE ALL IN ADDITION
     2TO THOSE REQUIRED BY THE [illegible] PROGRAM.*)
      WRITE(6,110)NSTABLE
  110 FORMAT( /,1H0, *NSTABLE = *,I2, *, -- 0 CALCULATES INTERFERENCE
     1 FORCES AT ALL INTERMEDIATE STEPS,*/,13X * -- 1 CALCULATES INTERF
     2ERENCE FORCES AT MAJOR TIME STEPS ONLY.*)
      WRITE(6,120)NEJECT
  120 FORMAT( /,1H0,*NEJECT = *I2*, -- 0 IMPLIES EJECTION CURVE IS FORC
     1E-DISTANCE,*,/,12X, * -- 1 IMPLIES EJECTION CURVE IS FORCE-TIME
     2.*)
      WRITE(6,130)NGAM
  130 FORMAT( /,1H0, *NGAM = *,I2, *, -- 0 IMPLIES FREE-AIR SIMULATION
     1,*,/12X, * -- 1 IMPLIES CAPTIVE TRAJECTORY SIMULATION.*)
      WRITE(6,135) NONMAX
  135 FORMAT( /,1H0,*NONMAX = *,I3,*, -- NONMAX IS THE MAXIMUM NUMBER O
     1F MAJOR TIME STEPS ALLOWED DURING TRAJECTORY SIMULATION.*)
      ANGATK=DUMMY
      RAD=180./PI
```

```
SUBROUTINE TRJREAD      74/74    OPT=0    TRACE                    FTN 4.1+P373        03/27/74

      READ(5,10)SMAX,YCG,SMASS,RGYRAY
      WRITE(6,140)SMAX,YCG,SMASS,RGYRAY
 140  FORMAT(///,1H0,  *STORE MAX RADIUS IN FEET = *,F10.4,/,
     1   * STORE CG BEHIND NOSE IN FEET = *,F10.4,/,
     2    * STORE MASS IN SLUGS = *,F10.4,/,
     3     * STORE Y-RADIUS OF GYRATION IN FEET = *,F10.4)
      YMOMIN=SMASS*RGYRAY*RGYRAY
 10   FORMAT(2F10.5)
      READ (5,405) VINF,GAMMA,RHO,G                                     TRJA657
      WRITE (6,435) VINF,GAMMA,RHO,G                                    TRJA658
      READ (5,405) CRD,VZERO,VAR(6)                                     TRJA659
      READ(5,405)C
      READ(5,405)D
      READ(5,10)CMU,YL1,YL2,EJEND1,EJEND2,EJANGL
      EJFCTR=COS(EJANGL/RAD)
      WRITE(6,150)C
 150  FORMAT(///,* EJECTOR ONE COEFFICIENTS = *,6(1XE12.4))
      WRITE(6,160)D
 160  FORMAT(* EJECTOR TWO COEFFICIENTS = *,6(1XE12.4))
      WRITE(6,170)EJEND1,EJEND2
 170  FORMAT(///,* EJECTOR ONE CUT-OFF ARGUMENT = *,F10.4,
     1/,* EJECTOR TWO CUT-OFF ARGUMENT = *,F10.4)
      WRITE(6,180)EJANGL
 180  FORMAT(* EJECTOR ANGLE IN DEGREES = *,F10.4)
      WRITE (6,415)                                                     TRJA660
      WRITE (6,435) CRD,VZERO,VAR(6)                                    TRJA661
      STR(1)=-ALPHA(1)
      VAR(3)=STR(NSTR)/RAD                                              TRJA662
      VAR(1)=YM(1)
      VAR(2)=-ZM(1)
      VAR(4)=-VZERO*SIN(VAR(3))                                         TRJA665
      VAR(5)=-VZERO*COS(VAR(3))                                         TRJA666
      THIN=VAR(3)                                                       TRJA667
      READ(5,405) DTIME,TIMEI,TIMEF,DTIME2
      NEQ=6                                                             TRJA669
      DDTIME=DTIME                                                      TRJA670
      TIME=TIMEI                                                        TRJA671
      ZINERT=VAR(2)
      IF (TIME.LE.0.0) GO TO 870                                        TRJA672
      READ (5,665A) VAR
      VAR(3)=VAR(3)/RAD                                                 TRJA674
      YM(1)=VAR(1)
      ZM(1)=-VAR(2)
      ALPHA(1)=-VAR(3)*RAD
  870 NDIFEQ=1                                                          TRJA675
      GO TO 872
 871  DTIME=DTIME2
      DDTIME=DTIME
      EJEND1=100.
      EJEND2=100.
      NDIFEQ=1
      DO 70 I=1,6
      C(I)=0.
      D(I)=0.
 70   CONTINUE
      CALL ADAMS(DTIME,DDTIME,VAR,DVAR,NEQ,NDIFEQ,TIME)
      NOUT=0
```

```
SUBROUTINE TRREAD      74/74    OPT=0    TRACE                  FTN 4.1+P373        08/27/74

                  RETURN
             872  CALL ADAMS(STIME,DDTIME,NVS,DVAR,NEQ,NDIFEQ,TIME)
                  NOUT=1                                                        TRJA677
                  REFARE=PI*SPMAX*SPMAX                                         TRJA678
                  REFLGH=SPMAX+SPMAX                                            TRJA679
                  VIECL=VINF*COS(GAME/RAD)                                      TRJA680
                  VIESF=VINF*SIN(GAME/RAD)                                      TRJA681
                  CONA=0.5*RHO*REFARE/SMASS                                     TRJA682
                  CONB=CONA*REFLGH/(EGYRAY**2)                                  TRJA683
              869 WRITE (6,436) REFARE,REFLGH                                   TRJA693
                  CALP=COS(ANGATK/RAD)                                          TRJA700
                  SALP=SIN(ANGATK/RAD)                                          TRJA701
                  XIN=VAR(1)*CALP+VAR(2)*SALP                                   TRJA702
                  ZIN=VAR(2)*CALP-VAR(1)*SALP                                   TRJA703
                  CGEAF=COS((GAME+ANGATK)/RAD)                                  TRJA704
                  SGEAF=SIN((GAME+ANGATK)/RAD)                                  TRJA705
                  VICAF=VINF*COS(ANGATK/RAD)                                    TRJA706
                  VISAF=VINF*SIN(ANGATK/RAD)                                    TRJA707
             C                                                                  TRJA708
             C    CALCULATE FORCES AND MOMENTS                                  TRJA709
             C                                                                  TRJA710
                  KODE=0
                  RETURN
                  END
```

SUBROUTINE TRAJEC   74/74   OPT=0   TRACE   FTN 4.1+P375   08/27/74

```
          SUBROUTINE TRAJEC(XMACH,KSTABLE)
C
C
C         CARDS IDENTIFIED IN COLUMNS 73-80 WITH "TRJAXXX", WHERE "XXX" IS
C         A THREE-DIGIT NUMBER, WERE TAKEN DIRECTLY THE GOODWIN MAIN PROGRAM
C         AND SUBROUTINES (SEE REAP TP 33)
C
C
          COMMON /TRAJ/                                    NRUN,KSTOP,CNI,CMI
          COMMON /C12/ XM(1),YM(1),ZM(1),XI(1),[illegible](1)
          COMMON /T[illegible]/ [illegible],[illegible],[illegible],[illegible](1),RGYRAY,YMOMIN,VINF,GAMF,
         1[illegible],[illegible],[illegible],VAR(6),[illegible],[illegible],[illegible],XL1,XL2,[illegible],[illegible],DTIME,
         2TIME1,TIME2,[illegible],TIME,[illegible],[illegible],[illegible],[illegible],[illegible],VISOF,
         3VISOF,CGNI,[illegible],CALP,SALF,[illegible],[illegible],CGFAF,SGFAF,VISAF,[illegible],D.AP(6),
         4ANGATK,[illegible],RAD,THIN,NEJECT,NGAM,NOFG,VISOF,FACTOR,ZINERT
  437 FORMAT(1H0,6X,6HTIME =,1PE11.4,1X,7HSECONDS)                         TRJA106
  440 FORMAT(//5X,[illegible] OF STORE CENTER OF GRAVITY AND STORE PITCHTRJA112
     1 ANGLE IN FUSELAGE WIND-AXIS SYSTEM/10X,[illegible] RELATIVE TO THTRJA113
     2E LOCATION THE C.G. WOULD HAVE BEEN IN AT THE ATTITUDE [illegible]/10X,  TRJA114
     34HSTORE WOULD HAVE HAD HAD IT REMAINED ATTACHED                   TRJA115
     42X[illegible] TO THE [illegible] AIRCRAFT//10X,[illegible],FT,                     TRJA116
     57X,[illegible], FT,[illegible], FT,[illegible],3(1PE16.4))                        TRJA117
  441 FORMAT(//5X,57H LOCATION OF STORE CENTER OF GRAVITY AND STORE PITCHTRJA118
     1 ANGLE IN FUSELAGE COORDINATE SYSTEM/10X,[illegible] RELATRJA119
     2TIVE TO FUSELAGE NOSE/10X,[illegible] PITCH ANGLE IS ANGLE BETWEEN FUSELAGETRJA120
     3 AXIS AND STORE AXIS//22X,[illegible], FT,10X,[illegible], FT,5X,[illegible]THETA, DEG, TRJA121
     4/14X,3(1PE16.4))                                                  TRJA122
  442 FORMAT(//5X,[illegible] VELOCITIES AND ACCELERATIONS OF STORE RELATIVE TO FTRJA123
     1USELAGE MOTION//26X,[illegible], FT/SEC,8X,[illegible], FT/SEC,[illegible]THETA,TRJA124
     2 RAD/SEC/[illegible],1PE11.4,8X,E11.4,11X,E11.4//17X,[illegible], FT/SEC/SEC, TRJA125
     33X,[illegible], FT/SEC/SEC,3X,[illegible]THETA, RAD/SEC/SEC/19X,E11.4,[illegible],   TRJA126
     4E11.4,11X,E11.4/)                                                 TRJA127
  443 FORMAT(/5X,[illegible]STORE/7X,22HFREE STREAM VELOCITY =,1PE12.4,7H FT/SEC/TRJA128
     17X,19HFLIGHT PATH ANGLE =,1PE12.4,4H DEG//,17HANGLE OF ATTACK =, TRJA129
     21PE12.4,4H DEG)                                                   TRJA130
  862 VARZD=VAR(4)                                                      TRJA711
      VARED=VAR(5)                                                      TRJA712
      VSTORE=SQRT((VISAF-VARZD)**2+(-VISAF+VARED)**2)                   TRJA713
      VSTOSQ=VSTORE*VSTORE                                              TRJA714
      VVERT=VISOF-VARZD*SGFAF+VARED*CGFAF                               TRJA715
      VHORI=VISOF-VARZD*CGFAF-VARED*SGFAF                               TRJA716
      GAMS=RAD*ATAN(VVERT/VHORI)                                        TRJA717
      IF (NGAM.NE.1) GAMS=GAMF                                          TRJA718
      ALFS=GAMF+ANGATK+RAD*VAR(3)-GAMS                                  TRJA719
      IF (NOUT.EQ.1) WRITE (6,437) TIME                                 TRJA720
      CALL [illegible](ALFS,XMACH,CNS,CMS)
C     CALL FORCE                                                        TRJA721
      FZ1=FZ2=0.
      EJARG=TIME
      IF(NEJECT .EQ. 0)EJARG=ABS(VAR(2)-ZINERT)/FACTOR
      IF(EJARG .LE. EJEND1)CALL EJECTR(C,EJARG,FZ1,FACTOR)
      IF(EJARG .LE. EJEND2)CALL EJECTR(D,EJARG,FZ2,FACTOR)


      XEMOM1=-FZ1*XL1
      XEMOM2=-FZ2*XL2
      QSB=CONV*YMOMIN*VSTOSQ
```

```
SUBROUTINE TRAJEC      74/74    OPT=0    TRACE                    FTN 4.1+P373        08/27/74

               QS=QSB/REFLGH
               CMEJ1=YFRCM1/QSP
               CMEJ2=YFRCM2/QSP
               CNEJ1=-F1/QS
               CNEJ2=-F2/QS
               CMDAMP=CMQ*(VAR(6)*REFLGH/(2.*VSTOPE))
               CNT=CNI+CNS+CNEJ1+CNEJ2
               CMT=CMI+CMS+CMEJ1+CMEJ2+CMDAMP
               IF(NOUT .EQ. 0)GO TO 100
               WRITE(6,707)CNI,CMI,CNS,CMS,CNEJ1,CMEJ1,CNEJ2,CMEJ2
               WRITE(6,708)CMDAMP,CNT,CMT
         100   CONTINUE
         707   FORMAT(// 5X,18HFORCES AND MOMENTS/26X,2HCN,11X,2HCM/7X,12HINTERFE
              1RENCE,2(1PE12.4)/7X,8HFREE AIR,5X,2(1PE12.4)//7X,12HEJECTOR ONE ,2(
              21PE12.4)/7X,12HEJECTOR TWO 2(1PE12.4))
         708   FORMAT(7X,7HDAMPING,17X,1PE12.4//7X,5HTOTAL,7X,2(1PE12.4))
               DVAR(1)=VAR(4)                                                      TRJA722
               DVAR(2)=VAR(5)                                                      TRJA723
               DVAR(3)=VAR(6)                                                      TRJA724
               DVAR(4)=C[illegible]*VSTOSQ*((  CNT  )*SIN(VAR(3))+CDO*COS((ANGATK+GAME-GA
              1MS)/RAD))+G[illegible]                                              TRJA725
               DVAR(5)=C[illegible]*VSTOSQ*((  CNT  )*COS(VAR(3))+CDO*SIN((ANGATK+GAME-GA
              1MS)/RAD))-G[illegible]                                              TRJA729
               DVAR(6)=C[illegible]*VSTOSQ*(  CMT  )
               IF (N[illegible].EQ. ) GO TO 860                                    TRJA730
               DUMA=RAD*(VAR(3)+THIN)                                              TRJA731
               [illegible]=VAR(1)*CALP-VAR(2)*SALP+XIN                             TRJA732
               DU[illegible]=VAR(2)*CALP-VAR(1)*SALP-ZIN                           TRJA733
               WRITE (6,440) DUMB,DUMC,DUMA                                        TRJA734
               DUMA=RAD*VAR(3)                                                     TRJA735
               WRITE (6,441) VAR(1),VAR(2),DUMA                                    TRJA736
               WRITE (6,442) DVAR                                                  TRJA737
               WRITE (6,443) VSTOPE,GAMS,ALPS                                      TRJA738
               NA=NSEG/5                                                           TRJA739
               NOUT=0                                                              TRJA749
               IF(NCONTR .GE. NONMAX)GO TO 49
               NCONTR=NCONTR+1
               IF((EJARG .LT. EJEND1) .OR. (EJARG .LT. EJEND2))GO TO 40
               KODE=1
               CALL TREAD(ANGATK,KODE,KSTABLE)
               GO TO 850
          40   IF (TIME*1.0E-06-TIMEF) 860,49,49                                   TRJA750
          49   KSTOP=1
               RETURN
         860   CALL ADAMS (DTIME,DDTIME,VAR,DVAR,NEQ,NOIFEQ,TIME)                  TRJA751
         880   IF (NOIFEQ.EQ.1) GO TO 49                                           TRJA752
               IF (NOIFEQ.GT.7) NOUT=1                                             TRJA753
               XM(1)=VAR(1)
               ZM(1)=-VAR(2)
               ALPHM(1)=-VAR(3)*RAD
               IF(KSTABLE .EQ. 0)RETURN
               IF(NOUT .EQ. 1)RETURN
               GO TO 862
               END
```

```
SUBROUTINE EJECTR     74/74    OPT=0    TRACE                FTN 4.1+P373        08/27/74

                  SUBROUTINE EJECTR(C,ARG,FZ,FAC)
                  DIMENSION C(6)
                  FZ=C(1)
                  DO 10 I=2,6
                  TEMP=ARG**(I-1)
                  FZ=FZ+C(I)*TEMP
             10   CONTINUE
                  FZ=FZ*FAC
                  RETURN
                  END
```

```
SUBROUTINE FREAIR      74/74    OPT=0    TRACE                  FTN 4.1+P373        08/27/74

      SUBROUTINE FREAIR(THETA,XMACH,CN,CM)
      DIMENSION TBXMTH(1[illegible]),TBYCN(36),TBYCM(36),NA(2),XA(2)
      DATA NA,K,M/4,9,1,3/
      DATA TBXMTH/0.,[illegible],[illegible],[illegible],0.,2.,4.,6.,8.,10.,12.,14.,15./
      DATA TBYCN/0.,[illegible],[illegible],[illegible],[illegible],[illegible],[illegible],1.03,1.14,
     1           0.,0.12,[illegible],[illegible],[illegible],[illegible],[illegible],1.13,1.14,
     2           0.,0.13,[illegible],0.41,[illegible],[illegible],[illegible],1.13,1.25,
     3           0.,0.13,[illegible],[illegible],[illegible],[illegible],[illegible],1.2[illegible],1.31/
      DATA TBYCM/0.,-.1[illegible],-.2[illegible],-.4[illegible],-.[illegible],-.[illegible],-1.[illegible],-1.634,-1.858,
     1           0.,-.137,-.304,-.4[illegible],-.[illegible],-.[illegible],-1.[illegible],-1.[illegible],-1.818,
     2           0.,-.1[illegible],-.2[illegible],-.5[illegible],-.[illegible],-1.085,-1.445,-1.825,-1.972,
     3           0.,-.193,-.412,-.627,-.[illegible]3,-1.178,-1.456,-1.566,-1.780/
      XA(1)=XMACH
      XA(2)=ABS(THETA)
      CN=TBLU[illegible](K,M,TBYCN,TBXMTH,NA,XA)
      CM=TBLU[illegible](K,M,TBYCM,TBXMTH,NA,XA)
      CM=CM*THETA/XA(2)
      CN=CN*THETA/XA(2)
      RETURN
      END
```

```
FUNCTION TBLNDC      74/74    OPT=0    TRACE                    FTN 4.1+P373        06/27/74

                  FUNCTION TBLNDC(NEXTR,ND,Z,Y,NA,XA)                            TBLND001
                  DIMENSION X(1),NA(1),XA(1),NS(5),NJ(20),RATIO(5),NGROUP(5),    TBLND045
                 1ITOT(5),Z(1)                                                   TBLND046
                  IF(ND.LE.6)GO TO 1                                             TBLND047
                  PRINT 2                                                        TBLND048
              2   FORMAT(1H1,10X,29HERROR CONDITION-TBLND ROUTINE)               TBLND049
                  PRINT 5, ND                                                    TBLND050
              5   FORMAT(11X,30HDIMENSION OF TABLE LOOK-UP (N=,                  TBLND051
                 1I2,19H) IS GREATER THAN 6)                                     TBLND052
              1   L1=2                                                           TBLND053
                  LF=ND-1                                                        TBLND054
                  DO 3 I=1,LF                                                    TBLND055
                  L2=L1+NA(I)-2                                                  TBLND056
                  FOUND=0.                                                       TBLND057
                  DO 4 J=L1,L2                                                   TBLND058
                  IF(X(J).GT.X(J-1)) GO TO 6                                     TBLND059
                  PRINT 2                                                        TBLND060
                  PRINT 40, I                                                    TBLND061
             40   FORMAT(11X,23HINDEPENDENT VECTOR NO. ,I2,20H IS NOT IN ASCENDING TBLND062
                 27H ORDER.)                                                     TBLND063
                  CALL SYSTEM(200,0)                                             TBLND064
                  STOP                                                           TBLND065
                6 IF (FOUND.NE.0.) GO TO 4                                       TBLND066
                  IF (XA(I)-X(J-1))8,4,4                                         TBLND067
                8 IF (J.NE.L1) GO TO 10                                          TBLND068
                  IF (NEXTR.EQ.0) GO TO 37                                       TBLND069
                  FOUND=1.                                                       TBLND070
                  NS(I)=L1-1                                                     TBLND071
                  GO TO 4                                                        TBLND072
               10 FOUND=1.                                                       TBLND073
                  NS(I)=J-2                                                      TBLND074
                4 CONTINUE                                                       TBLND075
                  IF (FOUND) 11,12,11                                            TBLND076
               12 IF (XA(I)-X(L2))13,13,14                                       TBLND077
               14 IF (NEXTR.NE.0) GO TO 13                                       TBLND078
             37   PRINT 2                                                        TBLND079
                  PRINT 41, I                                                    TBLND080
             41   FORMAT(11X,26HINDEPENDENT PARAMETER NO. ,I2,17H IS OUT OF RANGE TBLND081
                 244HOF CORRESPONDING INDEPENDENT VECTOR AND K=0.)               TBLND082
                  CALL SYSTEM(200,0)                                             TBLND083
                  STOP                                                           TBLND084
               13 NS(I)=L2-1                                                     TBLND085
               11 L1=L2+2                                                        TBLND086
                3 CONTINUE                                                       TBLND087
                  DO 15 I=1,LF                                                   TBLND090
                  K=NS(I)                                                        TBLND091
                  RATIO(I)=(XA(I)-X(K))/(X(K+1)-X(K))                            TBLND092
               15 CONTINUE                                                       TBLND094
                  NGROUP(1)=NS(1)                                                TBLND095
                  NSUM=NA(1)                                                     TBLND096
                  DO 16 I=2,LF                                                   TBLND097
                  NGROUP(I)=NS(I)-NSUM                                           TBLND098
                  NSUM=NSUM+NA(I)                                                TBLND099
               16 CONTINUE                                                       TBLND100
            C     IN NGROUP(I) IS THE SUBSCRIPT OF THE ITH VARIABLE SUCH         TBLND101
                  ITOT(LF)=1                                                     TBLND105
                  DO 17 I=2,LF                                                   TBLND107
```

```
FUNCTION TBLNDC      74/74    OPT=0    TRACE                  FTN 4.1+P373         08/27/74

              J=LF-I+1                                                  TBLND108
              ITOT(J)=ITOT(J+1)*NA(J+1)                                 TBLND109
           17 CONTINUE                                                  TBLND110
              KF=2**LF                                                  TBLND113
              NN=-2                                                     TBLND114
              DO 22 I=1,KF,2                                            TBLND115
              IFIRST=1                                                  TBLND116
              NN=NN+2                                                   TBLND117
              DO 21 J=1,LF                                              TBLND118
              MM=2**(J-1)                                               TBLND119
              IF(AND(MM,NN).EQ.0)GO TO 18                               TBLND120
              IMON=IGROUP(J)+1                                          TBLND121
              GO TO 19                                                  TBLND122
           18 IMON=NGROUP(J)                                            TBLND123
           19 IFIRST=IFIRST+(IMON-1)*ITOT(J)                            TBLND124
           21 CONTINUE                                                  TBLND125
              ISEC=IFIRST+ITOT(1)                                       TBLND126
              WJ(I)=Z(IFIRST)                                           TBLND127
              WJ(I+1)=Z(ISEC)                                           TBLND128
           22 CONTINUE                                                  TBLND129
              DO 24 I=1,LF                                              TBLND130
              KF=KF/2                                                   TBLND131
              DO 24 J=1,KF                                              TBLND132
           24 WJ(J)=WJ(2*J-1)+(WJ(2*J)-WJ(2*J-1))*RATIO(I)              TBLND133
              TBLNDC=WJ(1)                                              TBLND134
              RETURN                                                    TBLND135
              END                                                       TBLND136
```

```
SUBROUTINE ADAMS      74/74    OPT=0    TRACE                  FTN 4.1+P373        09/27/74

           SUBROUTINE ADAMS (H,DS,Y,DY,NEQ,NDIFEQ,S)                            TRJL  3
      C
      C
      C    ADAMS INTEGRATION ROUTINE                                            TRJL  1
      C                                                                         TRJL  2
      C    SUBROUTINE ADAMS TAKEN FROM GORDON (SEE NEAR TR 30)
      C
      C
           DIMENSION Y(1),DY(1)                                                 TRJL  4
           DIMENSION Y1(11),[illegible](11),Y5(11),[illegible],Y7(11),[illegible](11),[illegible](11),PY(11)TRJL  5
          1,[illegible](11),[illegible](11)                                     TRJL  6
           DATA [illegible],1.0E-24/                                            TRJL  7
           GO TO (100,200,300,400,500,600,700,800,900),NDIFEQ                   TRJL  8
      C                                                                         TRJL  9
      C    START BY RUNGE-KUTTA                                                 TRJL 10
      C                                                                         TRJL 11
       100 H=DS+DS                                                              TRJL 12
      1101 JB=1                                                                 TRJL 13
           DO 101 I=1,NEQ                                                       TRJL 14
       101 Y1(I)=Y(I)                                                           TRJL 15
       102 SY1=S                                                                TRJL 16
       103 NDIFEQ=2                                                             TRJL 17
           RETURN                                                               TRJL 18
       200 DO 201 I=1,NEQ                                                       TRJL 19
           DY3(I)=DY(I)                                                         TRJL 20
           Y5(I)=Y(I)                                                           TRJL 21
           TEMP=H*DY(I)                                                         TRJL 22
           Y(I)=0.5*TEMP+Y5(I)                                                  TRJL 23
       201 E(I)=TEMP                                                            TRJL 24
           S=0.5*H+S                                                            TRJL 25
           NDIFEQ=3                                                             TRJL 26
           RETURN                                                               TRJL 27
       300 DO 301 I=1,NEQ                                                       TRJL 28
           TEMP=H*DY(I)                                                         TRJL 29
           Y(I)=0.5*TEMP+Y5(I)                                                  TRJL 30
       301 E(I)=E(I)+2.0*TEMP                                                   TRJL 31
           NDIFEQ=4                                                             TRJL 32
           RETURN                                                               TRJL 33
       400 DO 401 I=1,NEQ                                                       TRJL 34
           TEMP=H*DY(I)                                                         TRJL 35
           Y(I)=Y5(I)+TEMP                                                      TRJL 36
       401 E(I)=E(I)+2.0*TEMP                                                   TRJL 37
           S=0.5*H+S                                                            TRJL 38
           NDIFEQ=5                                                             TRJL 39
           RETURN                                                               TRJL 40
       500 DO 501 I=1,NEQ                                                       TRJL 41
       501 Y(I)=(H*DY(I)+E(I))*0.16666667+Y5(I)                                 TRJL 42
           GO TO (502,507,508,3021),JB                                          TRJL 43
       502 DO 503 I=1,NEQ                                                       TRJL 44
       503 Y3(I)=Y(I)                                                           TRJL 45
           S=S-H                                                                TRJL 46
      5503 H=0.5*H                                                              TRJL 47
           TEMP=S+H                                                             TRJL 48
           IF (TEMP-S) 504,504,505                                              TRJL 49
       504 NDIFEQ=1                                                             TRJL 50
           WRITE (6,750)                                                        TRJL 51
       750 FORMAT(//44H  INTEGRATION INTERVAL HAS BECOME TOO SMALL./52H   HH NTRJL 52
```

```
SUBROUTINE ADAMS      74/74    OPT=0    TRACE                 FTN 4.1+P373        08/27/74

             1 IT IS ADDED TO INDEPENDENT VARIABLE, NO CHANGE RESULTS.)           TRJL  53
              RETURN                                                              TRJL  54
          505 JR=2                                                                TRJL  55
         5505 DO 506 I=1,NEQ                                                      TRJL  56
          506 Y(I)=Y1(I)                                                          TRJL  57
              GO TO 102                                                           TRJL  58
          507 DO 508 I=1,NEQ                                                      TRJL  59
              DY1(I)=DY3(I)                                                       TRJL  60
          508 Y2(I)=Y(I)                                                          TRJL  61
              JR=3                                                                TRJL  62
              GO TO 103                                                           TRJL  63
          509 S=S-H                                                               TRJL  64
        C                                                                         TRJL  65
        C     ERROR CHECKING                                                      TRJL  66
        C                                                                         TRJL  67
         5509 TEST=0.0                                                            TRJL  68
              DO 510 I=1,NEQ                                                      TRJL  69
              VX4=Y(I)                                                            TRJL  70
              TEMP= ABS(Y3(I)-VX4)                                                TRJL  71
              IF(TEMP .LE. 0.)GO TO 510
              VX4= ABS(VX4)                                                       TRJL  72
              IF(VX4 .LE. 0.)GO TO 512
              IF(ABS(Y3(I)) .LE. 0.)GO TO 512
        C                                                                         TRJL  73
        C     CHECK FOR RELATIVE ERROR                                            TRJL  74
        C                                                                         TRJL  75
              IF (VX4*RTEST-TEMP) 512,511,511                                     TRJL  76
          511 TEMP=TEMP/VX4                                                       TRJL  77
              GO TO 519                                                           TRJL  78
        C                                                                         TRJL  79
        C     CHECK FOR ABSOLUTE ERROR                                            TRJL  80
        C                                                                         TRJL  81
          512 IF (ATEST-TEMP) 514,514,513                                         TRJL  82
          513 TEMP=TEMP*RATIO                                                     TRJL  83
              GO TO 519                                                           TRJL  84
        C                                                                         TRJL  85
        C     BOTH TESTS FAIL. HALVE INTEGRATION INTERVAL.                        TRJL  86
        C                                                                         TRJL  87
          514 CONTINUE                                                            TRJL  88
          515 S=S-H                                                               TRJL  89
              IF (JR-5) 517,514,516                                               TRJL  90
          516 JR=1                                                                TRJL  91
              GO TO 5505                                                          TRJL  92
          517 DO 518 II=1,NEQ                                                     TRJL  93
          518 Y3(II)=Y2(II)                                                       TRJL  94
              GO TO 5503                                                          TRJL  95
          519 IF (TEST-TEMP) 520,510,510                                          TRJL  96
          520 TEST=TEMP                                                           TRJL  97
          510 CONTINUE                                                            TRJL  98
        C                                                                         TRJL  99
        C     OUTPUT OF RUNGE-KUTTA                                               TRJL 100
        C                                                                         TRJL 101
              IF (JR-4) 521,802,802                                               TRJL 102
          521 NDIFEQ=3                                                            TRJL 103
              DO 522 I=1,NEQ                                                      TRJL 104
              PX(I)=Y(I)                                                          TRJL 105
              PF(I)=DY(I)                                                         TRJL 106
```

```
SUBROUTINE ADAMS        74/74    OPT=0    TRACE                    FTN 4.1+P373        08/27/74

         522 Y(I)=Y2(I)
             RETURN
         800 DO 801 I=1,NEQ
             Y(I)=PX(I)
             DY(I)=PC(I)
         801 DY2(I)=DY3(I)
             JB=4
             S=S+H
         802 NDIFEQ=8
             RETURN
         900 IF (JB-5) 103,901,702
         901 CON=0.041666667*H
             JB=6
        9901 NDIFEQ=6
             GO TO 600
         902 JB=5
             TEST=FLD
             GO TO 802
      C
      C      ADAMS INTEGRATION
      C
         600 DO 601 I=1,NEQ
             Y1(I)=Y(I)
             Y(I)=Y(I)+CON*(55.0*DY(I)-59.0*DY3(I)+37.0*DY2(I)-9.0*DY1(I))
             DY1(I)=DY2(I)
             DY2(I)=DY3(I)
             DY3(I)=DY(I)
         601 Y3(I)=Y(I)
             S=S+H
             NDIFEQ=7
             RETURN
         700 DO 701 I=1,NEQ
         701 Y(I)=Y1(I)+CON*(9.0*DY(I)+19.0*DY3(I)-5.0*DY2(I)+DY1(I))
             GO TO 5509
      C
      C      TEST FOR DOUBLING OF INTEGRATION INTERVAL
      C
         702 IF (TEST-FLD) 703,9901,9901
         703 H=4.0*H
             GO TO 1101
             END
```

Vita

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[redacted] He attended The Ohio State University from June 1966 to December 1970, receiving his Bachelor of Science degree in Aeronautical and Astronautical Engineering. In March 1971 he began working at Wright-Patterson Air Force Base, Ohio, in the Airframe Directorate of Systems Engineering, Aeronautical Systems Division. In July 1973 he was given the opportunity to enroll in the Graduate Aeronautical Engineering program at the Air Force Institute of Technology.

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This thesis was typed by Jane Manemann.